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ANALOGY AND METAPHOR IN COSMOLOGY
A HISTORICAL AND METHODOLOGICAL ANALYSIS

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Abstract

The present article aims at analysing the modern conceptions of analogy and metaphor in Cosmology. In Cosmology metaphors function not only in the revealing context, but also in their explanatory context, as an important component of building new knowledge. These are explanatory and descriptive metaphors. The analogies in Cosmology play a crucial role in answering the question of the identity of the Universe as such - compared to other physical phenomena. Certain analogies and metaphors can be proved to be heuristically fertile and often lead to a significant semantic change in the interpretation of many phenomena and problems in physical cosmology. Based on 'analogue-inspired methodology' it can be said for example that modern Cosmology is in fact the experimental part of Science. We can successfully examine specific properties of the Universe in laboratory using analogies.

Keywords: Cosmology, analogies, metaphors, Philosophy of Science

Studying metaphor is one of the more fruitful ways of approaching fundamental logical, epistemological, and ontological issues central to any philosophical understanding of human experience.
(M. Johnson, *Metaphor in Content*)

1. Introduction - Why Science needs metaphor?

It is definitely possible to say that the second half of the twentieth century has retrieved metaphor for Science. Some even speak about a certain 'metaphor shift', citing numerous examples of it [1]. On the example of Cosmology, we show that metaphors function not only in the revealing context, but also in their explanatory context, as an important component of building new knowledge. These are explanatory and descriptive metaphors. From among some of the modern concepts of metaphor, we shall choose the ones that reflect the way this tool is used in Astronomy and Cosmology. We shall also point to those notions and processes in Cosmology, which are good examples of certain types in the

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classical theory of analogy. The goal of the paper is to show that certain analogies and metaphors can be proved to be heuristically fertile and often lead to a significant semantic change in the interpretation of many phenomena and problems in Physics. Based on 'analogue-inspired methodology' it can be said for example that modern Cosmology is in fact the experimental part of Science. We can successfully examine specific properties of the Universe in laboratory using analogies.

The problems with metaphor in Science are associated, among others, with the strong connotation of metaphor to the world of literature, and in particular - to poetry. This has too often deterred the philosophers of Science from dealing with metaphor in the context of Natural sciences, as it was thought to weaken the methodological status of sciences as logically ordered and unambiguous disciplines. The British empiricists criticized the presence of metaphors in Science claiming that they disrupted the quest for truth, which should be based on a literal description of reality [2]. What we need is therefore a clear meta-theory of metaphor, which would help us distinguish between the types and functions of metaphors, depending on the context in which they are used.

At every step we are accompanied by numerous metaphors and analogies that are so deeply rooted in the language that their use becomes indisputable and widely understood. Here are some examples of such metaphors: light *waves*, magnetic *resonance*, electric *current*, an elementary *charge*, magnetic *field*, a black *hole*, a *boundary* value, a derivative, solar *wind*, gravitational *lens*, *background* radiation, etc. The semantic process to which a metaphor is subjected in the course of creating or communicating knowledge makes a clear division between the living and dead metaphors: "Every metaphor, at the moment of its creation, is a semantic innovation, which makes it a living metaphor. However, if the way of understanding it in a given language is regulated by appropriate semantic conventions, it becomes a dead metaphor." [2, p. 133]

Let us point out, in the first place, to the reasons for using metaphor in Science. The image of Science, as presented by the widely understood scientific realism, is a process aimed at building scientific theories which are true, or approximately true. If it is so indeed, it seems reasonable to avoid metaphor in the process. From the methodological point of view it is not obvious at all that the aim of science is the truth, even in the traditional, correspondence sense. The debate over scientific realism and antirealism proves that cognitive contact with the empirical reality may also be entered into through various 'useful fictions', and that many elements of scientific models and theories perform a heuristic, temporary or auxiliary functions. This is where an indispensable part may be played by metaphors.

Another motive is related to education. Philosophers of Science dealing with the sociology of knowledge, such as Ludwik Fleck or Thomas Kuhn, argue that there is a certain hierarchy among academics when it comes to the transfer of knowledge [3]. Fleck distinguishes between different circles of scholars: some deal strictly with research, new discoveries, testing the developed theoretical tools, some, who have a content-based insight into the work of the first group, deal with didactics, while still others share knowledge on the popular level, with correct basic intuitions and result interpretations [3]. This process is aimed at spreading the results of scientific research to its recipients, who - although not being academics themselves - are still able to grasp the general idea of what scientific theories say about the world. Here as well, analogy and metaphor may play the key part in transferring the content behind the complicated apparatus of theoretical notions, reasonings and mathematical equations.

Cosmology is an especially adequate example of how any attempt at solving a problem is always connected to a certain methodological complex of empirical data, theoretical laws, cognitive values, ontological interpretations or heuristic rules, cosmological models, etc. For example: both the formulation and the solution of the famous Olbers paradox, may not be separated from a certain universe model.

Allow us to distinguish the basic functions of metaphors in the context of Science. The first of them is Catachresis, where a metaphorical concept is used in the process of creating a dictionary [4]. Such a function is performed by expressions such as ‘saddle’ in chaos theory or ‘black hole’ in Astrophysics. Thus, a concept is created which is bound to refer to a certain natural category, the existence of which we postulate. In Cosmology, this role is performed by expressions such as: ‘dark matter’ or ‘dark energy’. The second function of metaphors appears in popular science tests - a didactic function that helps non-scientists develop some basic cognitive intuitions. The third is the ontological function, where metaphors play a key, heuristic role in modelling. Often, the scientific models themselves are metaphorical.

The most important goal of the present article is an attempt at a methodological analysis of metaphors in the context of Cosmology. To this end, various concepts of metaphors will be reviewed, especially in the context of Natural sciences, taking into account the fact that this is a very ambiguous concept. We completely omit the role and functions of metaphors in literature. Let us note that metaphor has generally two fundamental features: in the expression ‘metaphor is a way to convey important intuition’ - ‘way’ as a metaphor refers to something that exists in reality (in this case, to the application of metaphor itself). Secondly, the fact that we recognize the meaning of a metaphor and its metaphoricality (i.e. the need for a non-literal treatment of the word ‘way’) on the basis of our empirical experiences with physical ‘ways’. Therefore, we advocate for a certain type of semantic and pragmatic realism in relation to metaphors that cannot be reduced to the syntax of logical relations between sentences.

The structure of this paper is as follows: 1. Analogy and metaphor in general, 2. Analogy and metaphor in physical science, 3. Analogy in Cosmology.

2. Metaphors and analogies in Philosophy and Science

Interestingly enough, the first part of the 20th century in the Philosophy of Science, dominated by logical empiricism, approached metaphors in Science with a great deal of distance, limiting their role to heuristics and didactic. Generally speaking, the assessment of a strictly scientific (science-forming) role of metaphor was very narrow: “Logical empiricists thought that metaphors, analogies (especially superficial ones) and naive parallelism had no cognitive value in science, and may lead to pseudo-knowledge, pseudo-explanation and pseudo-clarification” [5, p. 7]. Czarnocka and Mazurek point out to the fact that the problem of recognition of metaphors in science is connected to their classification as true expressions. What does it mean when we say a metaphor is true? In what sense can metaphor have cognitive function? Can Science function without metaphor?

It seems that Reichenbach’s differentiation between the context of discovery and the context of justification lead to metaphor being permanently located in the first of those contexts [6]. Nowadays it is known that Reichenbach’s selection is artificial in the sense that both contexts, together with their semantic tools, are interwoven. Metaphors and analogies do not disappear from Science neither in the didactic nor in the heuristic phase. In the present paper I prove that Reichenbach’s position is not entirely justified. Metaphors build up on the theory of analogy are an important component not only of creating the applicable knowledge, but also of the philosophical analysis thereof. Here, I would like to agree with Susan Haack, who encourages a balanced position on metaphor, claiming metaphor can lead both to valuable insight, but also - lead astray. “Metaphor is neither a Good Thing nor a Bad Thing in and of itself; it is, rather, a linguistic device capable of being put to a good or bad use, sometimes a help, sometimes harmless, sometimes a hindrance.” [7] According to Haack a good theory of metaphor is one which would be able to detect and describe its advantages and disadvantages at the same time.

Allow us to differentiate the following concepts of metaphor: comparative, substitutive, interactive (a concept developed by Max Black [8]) and explicative - formulated by Jerzy Kmita [9]). The first two are considered classic: the first one is based on analogy, the second is based on the theory of substitution. Kmita’s concept, most generally speaking, consists in showing that we are able to express a metaphor’s content with the aid of other sentences in a given language. Czarnocka and Mazurek, while analysing and criticizing different concepts of metaphor in Science, have pointed out to those that are especially effective. The use of metaphor is related to showing a certain similarity between two objects or systems of objects. This similarity is not an ontic addition to the comparative process, but rather is being discovered in the process [5]. What is perceived as the new, knowledge-creating, added value of a metaphor is the discovery of similarity itself. The definition of metaphor is thus: “A metaphor is a conclusion of deductive reasoning, the premises of which are the anticipated concrete version of the statement on similarity between the primary and the secondary object of the metaphor, and the knowledge of the secondary object of the metaphor" [5, p. 25]. The authors also rightly point out to the pragmatical aspect of metaphor in communication between scientists, who casually present certain intuitions to one another, without using complex language. In this sense, the use of metaphor is justified and 'true', as it is consciously a certain elliptic simplification.

For our analysis of analogy in the context of Cosmology, we shall use the traditional differentiation; firstly, the division into the analogy of being and conceptual analogy, analogical predication and inference. Among the analogies of being we shall point out to the analogy within being, which indicates a permanence of identity within the being in spite of the complexity and variable number of elements constituting the being. Secondly, the structural properties of being, its relations to the entirety of relationships it creates with other beings in a certain universe entirety testify to the occurrence of an analogy within being. In the context of the Universe as the subject of Cosmology, we shall pay attention to the relationships resulting from the fact that the Universe does in fact exists, that it is a being in itself, as well as to the relationships connected to the possibility of cognitive reception of the world's structure.

We shall point out to the analogy of assignment, in which a predicate, such as for example 'healthy' in the expression 'healthy air' is understood by analogy, because first it referred to a, for example healthy person. Other type of a typical analogy in Science is the analogical inference, especially connected to the heuristic value of reasoning, in which some features, traits and ore relationships are transferred from already known objects to those we wish to know. Analogical inference in Science is characterized by a large use of the researcher's intuition and imagination, and, although not being completely fool proof, tit has still lead to many significant discoveries. In Haack's concept of metaphor, a metaphor is, first of all, an elliptic comparison, which is figurative (tropic) [7]. Rom Harré conceives his concept of analogy and metaphor in Science on the basis of the role played by models in the interaction between the theoretical sphere and the phenomenal sphere [10]. In the context of Cosmology, this approach is particularly justified due to the special role played by models as largely autonomous tools in the process of testing scientific theories.

The discussion of the role of analogy and metaphor in Science is usually based on the function of models and the relation thereof to both - the referred theory and the described phenomenon. The structure of the explanation proposed by Harré is as follows: in the centre there is a scientific theory, which is connected to a physical phenomenon by a descriptive model, and to a cause-effect (or reduction) mechanism, on which the phenomenon is founded - by an explanatory model [10, p. 2]. It is therefore visible, that based on a theory, different kinds of models are formed - essentially two: explanatory and descriptive models. The function of descriptive models is to simplify the phenomenon through idealization or abstraction. Explanatory models are used in order to fill a gap in our knowledge. They are, according to Harré, in fact analogies. Often, the above-mentioned explanatory and descriptive functions are performed not by two separate models, but by two separate aspects of the same model.

Let us recall two approaches to scientific theory that point to various tasks of models in the relationship between a theory and a phenomenon. In the sentence approach, a theory is first and foremost a logical relationship between sentences, the foundation of which consists of a set of rules and assumptions characteristic of a given theory. An explanation in this approach has a deductive-nomological nature. In the second approach, a theory is treated as a set of models, where not the logical (deductive) relationships are being exposed, but there occurs the relation of a certain mapping between the world of phenomena and theory with the use of models. The models perform an intermediary function here. In such a conceptual scheme, we deal with a dual function of models or with pairs of related models, one of which is descriptive (it represents a phenomenon) and the other is explanatory - it represents a mechanism that generates the phenomenon (is a certain representative of an unobservable causal structure). Harré points out that this kind of an explanatory model is only an analogy to the real cause existing in nature. The similarity of the model to the physical system must always reflect a certain balance between the accuracy of matching to a certain physical situation - which often makes the model extremely complicated - and its simplicity, which increases the ease of use of the model.

We must also take into account that a model cannot by definition be a copy of a specific physical system, because it inherits what was occasional in this system. The effect of scientific activity should after all be the detection and theoretical description of certain general laws that refer to a particular class of phenomena of a certain type (gravitational, electromagnetic, etc.). Therefore, it seems useful to distinguish between descriptive models that emphasize the accuracy of presentation of the physical situation, and explanatory models that seek a deeper dependence by analogy. Usually, the biggest trouble with such a generally formulated concept of analogy is related to the fact that in analogy-based models it is very difficult to distinguish between their positive aspects (where does the analogy express real similarities?), negative aspects (whether such features of the modelled system can be distinguished, to which the analogy certainly does not apply?), and neutral aspects (that is all properties of the model that are non-essential to it, but otherwise auxiliary and necessary).

Allow us to distinguish two ways of dealing with the problem of adequacy of analogy. First of them is of epistemological nature, where we estimate the model with the help of reasoning resembling Mill’s Canons or Bayesian inference. The second way is to attach some ontological assumptions to the model. Ontological assumptions are nothing else than, for example, placing the model in a certain hierarchy of physical interactions. The models of the solar system and Bohr’s structure of the atom are divided by the ontology of a completely different context of physical interactions. This helps avoid misunderstandings regarding, for example, the physical interpretation of electron and planetary orbits.

It is worth pointing out to a certain, seemingly obvious, feature of models, namely the possibility to experiment with the model without the necessity to use measuring instruments. Instruments only enable us to examine the current state of a physical system, while saying nothing about its behaviour in another state. The use of a model allows us for making predictions of the system's behaviour (or rather the model's behaviour). A lot has been said about the fact that Astronomy and Cosmology leave no place for experiment, which in the traditional scientific nomenclature is defined as 'provoked observation'. In the world of cosmological models, we may still speak about experimenting on models. In this case the situation described as 'the degeneration problem' (many different models describe the phenomenon comparably well) becomes paradoxically a virtue of the model experiment methodology. (This function is performed by the so-called *toy models*.) Of course, an examination of the model's behaviour makes sense only in relation to a chosen physical phenomenon, when the analogical nature of the phenomenon is recognized adequately enough. The most important part of Harré's proposal is the fact that it puts the category of analogical similarity between the model and a physical system into the context of hierarchic physical ontology. Models in this concept, therefore, may not be mere sets of sentences and relationships between them. "The models themselves are not static sets of propositions. They are instead objects or object-like iconic dynamic representations of objects - natural kinds and relations between them, and the type hierarchy generates salience and similarity through inheritance and the empirically determined ordering of these kinds." [10, p. 11-12]

It has already been said that understanding of the analogical function of scientific models is closely related to the ontological context in which they are used. How is this methodological analysis made? Joke Meheus points out that this context consists of the following elements: 1) a problem to be solved, 2) certainties (meaning: necessary elements), 3) relevant elements, 4) methodological instructions [11]. In the case of Cosmology, to certainties we may include, for example, the General Theory of Relativity on which the cosmological model is built. This does not mean, of course, that we regard it as true in the absolute sense, but that we treat it as a certainty in the given modelling process. Also the type of logic or mathematical operations used for constructing the model may be considered certainties. Some of the relevant elements include, for example, empirical data, their type, specificity and properties, as well as the applied idealizations, the cosmological principle, which aim to narrow down the possible solutions of theoretical equations to a certain class of cases.

Analogies are often divided into weak and strong ones. The first kind are those that only have a heuristic function: they give a hint of how to solve a certain problem. Strong analogies, on the other hand, not only have a heuristic function, but they provide arguments themselves for accepting such and no other solution to the problem. In the field of Cosmology, it seems that the cosmological principle may serve as an example of a strong analogy, but only in the phase of research that allows for it to be tested. Then it becomes not only a methodological operation allowing for an easier solution to Einstein's equations, but also indicates the Universe's properties in an appropriately larger scale.

3. Analogies and metaphors in Cosmology

3.1. Astronomical and cosmological analogies and metaphors in the history of reflection on the Universe

The most fruitful metaphors and the strongest analogies are those that lead the researcher to new beliefs. What is more, they may provide valuable arguments in favour of these beliefs in themselves. Gerard Simon quotes a very interesting metaphor formulated by Kepler to explain the functioning of the eye: "the eye works as a darkroom, where on a screen we can see the upside-down image of external objects. The iris is like a diaphragm, which allows for widening and narrowing the 'window' of the pupil; transparent lenses act as focusing lenses, while the retina becomes a screen on which, due to the lenses, light beams reflecting from all parts of the object converge." [12]

Carlo Rovelli made a very interesting thesis in his work on the physics of Aristotle, namely that the formal relationship between Aristotle's physics and Newton's physics is analogous to the relationship between Newton's physics and Einstein's physics [C. Rovelli, *Aristotle's Physics*, 2013, https://philpapers.org/rec/ROVAP]. Aristotle's physics uses two notions of motion: violent motion (triggered by the action of someone who, for example, threw a stone) and natural motion (the motion of bodies left to themselves). Violent motion ends with the rest of the body once it uses up the momentum given to it by the cause of the motion. Natural motion takes two forms: the circular motion of the ether and the vertical motion of the Earth, air, water and fire. As Rovelli observes, these metaphors of violent and natural motion find their counterparts in Newton's theory, though they undergo a conceptual metamorphosis. The natural motion in Newtonian physics is the uniform linear motion, while violent motion - the accelerated motion.

Edward Harrison in his *Cosmology* recalls many metaphorical comparisons related to the individual properties of the Universe, such as the problem of the limits and edges of the Universe [13]. Let us briefly summarize certain phases of attempts to unravel the mysteries of the edges of the Universe. According to the atomists and Epicureans, the Universe was infinite, without a centre or any edges. It also had no end and no boundaries, as it had not been created by anything external to it. Aristotle and his heirs declared that the Universe was finite and thus had a centre and an edge. The border of the Universe was the sphere containing stars, which sealed it like a wall. Even Kepler shared the view that the Universe was limited, enclosed in a sort of cosmic dark wall. Kepler's arguments indicated that he was convinced that an infinite Universe would lead to the so-called Olbers' paradox, an interesting formulation of which was made by Archytas from Tarentum; "What happens with an arrow that crosses the boundaries of the Universe? Will it disappear from this world?" [13, p. 149] We thus fall into a logical paradox: what does that mean to cross the boundaries of the Universe, cease being its part? The same conclusion may be achieved by reasoning that something that is limited (has limits) is limited by something else, and yet the Universe is everything that exists. In the Post-Aristotelian (mainly Neoplatonic and medieval) attempts to deal with the problem of the physically limited universe, solutions were proposed stating that the Universe has boundaries, yet it is not limited suddenly but gradually. The Stoics' universe consisted of a finite outer space of stars surrounded by an infinite void without stars. The border of the Universe understood in this way may be compared not to the wall, but to a cliff above a sea, which divides the universe into two zones: the inner world consisting of stars and the world 'beyond the cliff', which consists of an empty space extending into infinity.

An extremely interesting and instructive example of the use of metaphors in astronomy and cosmology can be found in historical considerations concerning extra-galactic objects perceived from the Earth. The first important discovery, made due to the improving quality of the measurement tools, concerned the Milky Way, and therefore the observation of the fact that the stars are not evenly distributed on the celestial sphere. One of the researchers who presented these findings was Thomas Wright (1711-1786) in his 'An Original Theory of the Universe' [14]. He proposed two models of the Milky Way: in the form of a ring and a sphere (a spherical shell composed of stars). Wright also proposed that there were other clusters of stars outside the Galaxy. He called them other centres of creation. Kant developed the idea of the shape of the Milky Way as a disk or lens (in *Universal Natural History and Theory of the Heavens* [15]). Von Humboldt in his book *Kosmos* from 1855 presented the idea of island universes, where galaxies are islands. In this conceptual schema, stoic cosmology can be treated as a one-island cosmos, while the Epicurial cosmology (the atomists) as a multi-island universe. Benoit Mandelbrot introduced the concept of fractal universes. Laplace in his work *System of the World* (1796) [16] proposed a model for creating stars from a swirling and interacting cloud of interstellar dust. This nebula concept uses the cloud metaphor (from Latin *nebula* - cloud).

The distant galaxies were still perceived simply as clouds of star dust that served to create stars. The discovery of distant galaxies as a collection of stars was made due to the observations of William Herschel (1738-1822) [17]. On the basis of his observations, Herschel formulated three theses (all of them later turned out to be wrong): 1) the interstellar space is translucent for the light coming from the stars, 2) all stars are similar to the Sun, 3) the stars are evenly distributed in space. According to the following three hypotheses regarding nebulae functioned in the 18^{th} and 19^{th} centuries, nebulae were: 1) distant galaxies, similar to the Milky Way (an idea resembling the Kant-Wright island universe), 2) clouds of spinning gas, which concentrates in the form of stars and planets (a transformation of the Kant-Laplace hypothesis of clouds of interstellar gas), 3) an area of unbound stars on the outskirts of the galaxy. The cosmological model considered to be the standard associated with the so-called Victorian era (second half of the nineteenth century) in several theses (this image is summarized in the book by Agnes Clerke - an outstanding nineteenth-century historian of astronomy - *The System of the Stars* [18]): 1) a single island universe, 2) the Earth and Sun located in the centre of the galaxy, 3) a galaxy consisting of about one billion stars and star clouds.

3.2. Analogies and metaphors in modern Cosmology

Before we move on to the analysis of several chosen metaphors in modern Cosmology, let us first remind a classical differentiation of the theory of analogy, which should make the methodological analysis of each case easier. First of all, let us consider the Analogy Within Being. I should quote Harrison's differentiation between the Universe (the physical Universe we live in) and universes (models of the Universe). Firstly, Einstein's formulation of the cosmological problem is an example of an analogy within being. At the beginning of the 21st century, Cosmology became definitely a physical science, as observation tools allowed for the testing of cosmological observables constructed on the basis of a given model. The universe became in a way 'ours'.

The analogies of being in Cosmology play a crucial role in answering the question of the identity of the world as such. Any reconstruction of the Universe's dynamics is connected with the fact that the Universe is still the same entity. It is worth noting the proposals regarding the so-called anthropic principles or categories of the multiverse. They are, in fact, strong metaphysical assumptions ruling about the Universe, its existence and properties in terms of necessity: 'the Universe not only exists, but it also must be the way it is' or 'there exists everything that is possible'. The analogy of being connected with the intelligibility of the Universe in the case of Cosmology has some specific features. First of all, the subject recognizing the Universe is part of it. Testing the topological structure is done from within. The case is similar with the statement of the initial conditions for the Universe and the dynamic of its evolution: they are also not given externally, as in the case of a pendulum, but they are the internal property of the entire physical system which is studied.

The analogy of cognition in relation to the Universe is expressed in particular in the necessity of adopting certain metaphysical assumptions - the cosmological principles. The problem of horizons in cosmology and therefore of some natural cognitive limitations, in a way, provokes analogical inferences, where we deduce from the properties of parts of the Universe about the properties of the whole assuming that it is approximately uniform on a large scale. One of the most significant analogies and metaphors in the history of Cosmology is Newton's insight on the analogy between the fall of the body on the surface of the Earth and the movement of the Moon in Earth's orbit, which in fact has the same nature of 'falling'. Gustaaf Cornelis discusses a very interesting analogy used in 20th century cosmology by George Gamow [19].

Taking the so-called helium paradox (the problem with explaining the present amount of helium in space, as the stars in the process of fusion could not have produced so much of it) as a starting point, Gamow envisioned the Universe as a star. Thus, the conditions in the early Universe should similarly resemble those inside of a star. The early Universe should therefore be hot enough and thick enough for thermonuclear reactions to occur. Cornelis reconstructs the structure of analogical reasoning as follows [20]: The content of the analogy: a star is hot, thus the (early) Universe is also hot. The structure of reasoning: 1) we observe a large amount of helium in the Universe, while the stars only produce a part of it; 2) the stars are hot; 3) the Universe can also be hot; 4) thus, the Universe can have the properties of a star; 5) thus, the Universe can produce helium; 6) the Universe is hot.

Another analogy the between the stars and the Universe is related to the works of Roger Penrose and Stephen Hawking [21]. Penrose proved that, according to the General Theory of Relativity (GTR), a collapsing star can lead to a singularity. What's more, the occurrence of singularities turned out to be an internal property of the GTW (the fact that stars in the evolutionary stage of a black hole not only do exist, but are necessary to exist). This reasoning concerning the local spacetime was transferred by analogy to global spacetime [22]. Similarly to Gamow's analogy, a star became a metaphor for the entire Universe. If the Universe collapsed like a star, this would lead to a singularity forming. What is more, because of the symmetry of the GRT equations to time, the analogy begins to live its own life (does not apply to the star anymore) – one can reconstruct the past of the Universe in the direction of the original singularity. "(...) the singularity in the star's future is seen as the final stage of its evolution; the ultimate singularity of the Universe is at the same time the beginning of its history" [20, p. 169].

Another interesting analogy from that period of Cosmology development is the thermodynamic analogy associated with the black holes emitting radiation. Because black holes absorb all matter from their surroundings gravitationally, analogically to thermodynamic phenomena, they can be assigned the property of entropy. Since they have entropy, analogically one should also be able to speak about their temperature, which leads to the conclusion that they should emit radiation. The analogy used at the beginning seemed barren, as it seemed that black holes by nature do not emit anything. The works of Yakov Zeldovich and Alexander Starobinski showed that it is possible to refer the Heisenberg uncertainty principle to black holes, which in this case predicted the emission of virtual particles. In 1974, Hawking published a paper explaining the mechanism of the emission of some of virtual particles in black holes [23].

Let us note, that the last two analogies connected with black hole physics were not used in order to resolve a real, visible problem, but were transferred from one object to another (a black hole - the Universe, thermodynamics - black hole) and as such they have generated a completely new problem concerning the target object, thus unexpectedly leading to some new knowledge. Besides, the metaphors used work only in one direction. On the other hand, the analogy between the processes inside a star and the processes of the early Universe, noticed and applied by Gamow, was used to solve a problem that already existed. It can also be said that the problem of the excess amount of helium in the Universe has acted two ways; to develop the Astrophysics of stars, as well as to bring up speculations about the possibility of thermonuclear reactions in the early phase of the Universe's existence. This is an example of reasoning showing features of an interactive metaphor according to Max Black.

In the modern Cosmology we find a concept of analogue models of gravity. When we try to model various phenomena for example of general relativity we often use other physical systems (acoustics in a moving fluid, from condensed matter analogies to classical general relativity problems, Bose-Einstein condensates as a working fluid). According to C. Barcelo, S Liberati and M. Visser: "Analogue gravity is a research programme which investigates analogues of general relativistic gravitational fields within other physical systems, typically but not exclusively condensed matter systems, with the aim of gaining new insights into their corresponding problems" [24]. For example, analogue spacetimes have been used as 'toy models' for quantum gravity, fluid dynamics as an effective model in examining certain aspects of quantum field theory, analogue-based models of black-hole accretion. These analogues (or analogies) serve to provide new ways of looking at problems and lead to practical experiments which using the analogue can successfully resolve a given problem or better understand phenomenon.

Allow us now to consider an example of a negative metaphor, which rather impeded the perception of certain conceptual consequences of the General Relativity: it is a metaphor of space and time as a scene on which physical phenomena take place. The Newtonian metaphor makes us see the world in terms of physical processes taking place on a certain rigid stage. Unbinding time from space and thinking in such categories is a characteristic feature of this style of thinking. Certain errors in the understanding of cosmological expansion have their origin in these non-relativistic intuitions, according to which the model of the Universe is not treated as space-time: an integral whole, but separately as space and time. These are the consequences of thinking about the relativist theory in Newtonian terms [25].

Authors of popular books that aim at explaining the expansion of the Universe often use the metaphor of bread dough with raisins, or a balloon being blown up with astronomical objects (galaxies) marked on its surface. Growing dough or an expanding balloon are meant to illustrate the effect of the Universe systematically expanding. Let us notice that each of these metaphors contains a consolidation of the stereotype, according to which a balloon or a raisin bread exist in an external three-dimensional Euclidean space, which is fiction, as the Universe is not immersed in any sort of a meta-space. Such a way of thinking is on the one hand a reference to our intuition of seeing things in R^3, and on the other hand, it is the consolidation of the Newtonian style of thought.

The conclusion is as follows: we are unable to see the physical processes taking place in space-time in the same way that we are unable to see an object without its immersion in the background of space around it. The concept of space-time, unifying the concepts of time and space is constructed in such a way that the laws of physics can refer to it, while it ceases to be a perceivable object. The physical processes taking place in the Universe are not passive - they are actively shaping space-time. The curvature of space is a measure of the processes occurring within it. Space has an internal structure and is a dynamic creation. Its expansion is a physical phenomenon as such. Even empty space without matter or physical fields keeps expanding.

Another metaphor that proved to be heuristically fertile and has also led to a semantic change was the interpretation of the shift towards red in the spectrum of light of distant objects (the so-called redshift) by analogy to the Doppler effect. The context to this problem is the observational context to the emergence of the idea of an expanding universe. In the second decade of the 20th century, the American astronomer Vesto M. Slipher measured the shifts of spectral lines of 25 galaxies (then called spiral nebulae) and made a Doppler interpretation of these shifts [13, p. 271]. Four of them had red-shifted spectra, which meant that these galaxies were moving away. These were the first of many astronomical observations, the results of which confirmed the phenomenon of galactic escape.

This phenomenon can be interpreted classically in Doppler sense as the kinematic effect of moving away from objects in static space [26] or as an effect of the expansion of the entire space-time in the relativistic spirit [27]. Georges Lemaître was the one who distinguished these interpretations and pointed out to the one that has cosmological justification [28]. He also coined the term ‘apparent Doppler effect’. Lemaître’s creative use of the Doppler metaphor and the transformation of its significance in the relativistic context consisted in the association of redshift in distant galaxies with the expansion of the Universe, while Humason, Hubble or Tolman did not see the reason for combining it with Einstein’s theory of relativity, and even when the redshift found its cosmological interpretation, they tended to considered this effect as a purely kinematic phenomenon within Milne’s cosmology [13, p. 273]. A relativistic interpretation of redshift met with resistance from some cosmologists - for example Hubble refused to accept the cosmological interpretation. The astronomical circles have long been unwilling to accept a new cosmological interpretation (of space expansion) [29].

In the environment of astronomers influenced by the traditional understanding of the Doppler effect within static Newtonian space, the relationship discovered by Hubble has been identified with the escape of galaxies interpreted as a kinematic local effect. This interpretation is imposed by the Newtonian paradigm based on the experience of a certain form of perception. In describing the action of metaphors, however, we have indicated their double source: some empirical experience and a theoretical conceptual scheme. The Doppler effect becomes attractive and fertile for the relativists in the sense that the expansion of the Universe, for them, seemed to be the simplest explanation of Hubble's law. The same applies to the explanation of other well-known paradoxes that appeared at attempts to use Newton's theory to build a cosmological model (the photometric and gravitational paradoxes).

4. Conclusions

The concept of analogy has its strong philosophical roots, but nonetheless it remains ambiguous in framework of Philosophy and Science, as well. We distinguish mainly philosophical analogies in the field of Ontology (analogy of being) and Epistemology (semantic analogy). In Metaphysics we deal with transcendental or categorial analogies. When we speak about different objects, we use analogies as conceptual attribution or proportionality. Metaphor is the type of analogy which is based on the differences and similarities between compared objects, but the source of metaphorical relations remains in our mental perception. So, using metaphors we can speak of analogical cognition. Zbigniew Wolak elaborates very interesting examples of analogies in physics as relations which evolves in time [30].

In science analogies in general are used as heuristic conceptual tools which lead to understanding given phenomena and discovery. Analogies based on similarities between mathematical formalism are a special strong form of analogical relation - *nomic isomorphism*. Of course, the analogical reasoning can be quite weak (analogy of likeness) or even eventually inadequate.

The use of metaphors is deeply rooted in the current picture of the world at the time of emergence of scientific theories. Of course, in the process of reconstructing the justification for the theory itself, the subtle connections and influences usually disappear. Nevertheless, in the context of the discovery, our world-view and certain philosophical beliefs certainly do shape our predilection to metaphor. Fernand Hallyn, when describing the relationship between the alphabet and the concepts of atomism in European antiquity, noted down an interesting remark: "One can only remark that a civilisation which does not know alphabetical writing, like the Chinese civilisation, did not develop an atomistic hypothesis, which thus probably has a definite cultural rooting" [31].

Concerning metaphors in science in the most general sense, it must be said that they perform functions other than the remaining theoretical tools: they describe and transmit information. It is commonly believed that the introduction of a metaphor in relation to a certain thing or phenomenon is connected with the fact that a new set of predicates is created, which are attributed to this phenomenon/thing. A powerful and legitimate metaphor in the context of Science can be spoken of when we assume that there is no established set of so-called standard predicates to determine the properties of a certain object in nature [32]. Of course, this is an anti-realist thesis, at least at description level. The concept of atomic orbitals, which is rooted in the planetary analogy of the atomic model, is an example of scientific fiction that is still in use in chemical practice.

We argue that metaphors are involved in the methodology of scientific explanation, and as such they have a complex structure. To order the above discussion, theories about metaphors can be divided into four types. First of them is where the metaphor consists in referring an object's name to another object and examining the semantic contrast between the two objects. This concept of metaphor is called the demonstrative concept. The second approach to metaphor lies in exposing different meanings of the same language expression. This sometimes leads to establishing a completely new connotation of the same word. The third concept functions rather on the level of sentences that combine two concepts with a certain metaphorical tension. This conceptual scheme may be illustrated with an image from Max Black's work: a sentence containing a metaphor connects two object domains, between which a peculiar two-way transfer of meaning then takes place [8, p. 27]. The fourth group of ideas regarding the nature of metaphor is pragmatic. A metaphor here consists in creating a certain type of tension, polarization between the expected and obtained use of a linguistic expression.

The explanatory character of metaphors in science can be demonstrated by showing that in the use of a metaphor we are dealing with the choice and understanding of a specific transformation of meaning between the original context from which we derive the predicate that later becomes our metaphor and the target context. We support the notion that the methodology of using metaphors consists in combining concept with experience. A condition to understanding a metaphor is having experience with the metaphorical expression in its original contexts. One could even say that the process of using metaphors is of experimental nature - there is something resembling the testing of semantic postulates, which is why some metaphors turn out to be completely inaccurate, while others settle permanently in scientific language.

In the context of Physics, the use of metaphors seems particularly justified by the fact that in the process of confronting a physical theory - expressed in the formalized language of Mathematics - with experience, we want to achieve a coherent cognitive and interpretive image. Several important elements can be distinguished in this process. Firstly, metaphors in Physics appear in the discovery phase of scientific theories. Both the construction of a metaphor and its understanding and assimilation have a discovery nature. It is often the case that the metaphor is so 'expansive', that it acquires a radically different meaning from the one that had been in force so far (e.g. the astrophysical metaphor of the 'black hole'). Secondly, metaphors in science are often used to represent concepts that are constructed and used by scientific theories. We agree with the view that a theoretical model can be interpreted as a metaphor's representation [1]. Guichun mentions two such functions of representation: the ontological function (such as 'quark', 'gene') and the spatial function; metaphor does not refer to a physical object, but it is a kind of an expression of some physical properties and their relations (e.g. 'Schroedinger cat').

An analysis of metaphor in the past and contemporary cosmology has shown, first of all, their diversity and, what is more, their creative operability. Firstly, the metaphors had the character of a one-way relationship, where a certain transfer of physical properties was made from the primary to the secondary system on the basis of a certain analogy. Secondly, the analogies manifested associations with certain cosmological models. It can be said that a model is founded on a specific metaphor, especially in the phase of its founding [33]. Thirdly, metaphors and analogies in Cosmology occurred in two methodological contexts: 1) a certain problem is given, for which a solution is sought (first a problem - then a metaphor); 2) the use of metaphorical analogy leads to the perception and detection of a problematic situation (first a metaphor - then a problem). Fourthly, metaphors in cosmology play a part not only in the discovery phase, but also in the justification phase, which, thanks to metaphor, leads to the creative processing of the issue. Fifth, in the interpretation of cosmological metaphors, Harré's theory of hierarchy turns out to be particularly useful [10]. The metaphorical activity cannot be separated from a certain ontological order, in which we use the metaphor, as indicated by examples of metaphors associated with the relativistic or Newtonian concepts of time and space. Although we can select cosmological models at cognitive level (for example on the basis of the Bayesian methodology), ontological references are indispensable for understanding and effective application of metaphors.

Generally speaking, the role of analogy in Physics is foremost in the context of discovery, not justification. Analogies and metaphors are used also as the tools for transmission of a scientific knowledge in more popular way that can be perceived in society. That is why popular books about Science are so popular and often become bestsellers. They are full of metaphors (not always properly presented and understood), and therefore even most difficult scientific problems and their solutions become in fact the part of culture.

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