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GEORGES LEMAÎTRE'S CONTRIBUTION TO THE FORMATION OF THE DYNAMIC VIEW OF THE UNIVERSE

I. INTRODUCTION

The history of science offers us many examples of so-called scientific revolutions according to which the development of human knowledge is not progressed by simple accumulation but in a discontinuous way. New scientific theories are very often quite different from the old ones. They not only propose new solutions but also stand in opposition to hitherto existing theories and frequently they deny and even contradict them.

Certainly, the transition from a static to dynamic view of the Universe can be called such scientific revolution. For a long time, until the nineteen thirties, there existed the common conviction that the Universe as a whole had its properties fixed once and forever. This meant that the Universe not only did not change its spatial dimensions with time but also that it preserved the same average picture of its structure, independently of the passage of time. It was understood that the Universe was unchanging in its large-scale dimensions although some local motions of the heavenly bodies could be observed. These motions, however, were too small compared with the size of the whole Universe thus they could not have had any influence on its general picture.

Such a view of the Universe was supported not only by philosophical reasons but also by the state of the then astronomical observations. They gave no express suggestions about the large-scale motion of the Universe. Even Wilhelm de Sitter, with his extensive knowledge of current astronomy had no hesitation in holding that the Universe as a whole should be regarded as a static[1]. The belief in a static Universe was so deeply rooted in the scientific community that the founder of the Relativity Theory not only accepted it as a principal assumption to construct a cosmological model, but also preferred to change his field equations to satisfy this opinion[2]. Because of this Einstein also

[1] W. de Sitter, *On Einstein's Theory of Gravitation and its Astronomical Consequences III*, „Monthly Not. Roy. Astron. Soc.", 78(1917)3-28; J.D. North, *The Measure of the Universe. A History of Modern Cosmology*, Oxford 1965, s. 87-104.

[2] A. Einstein, *Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie*, „Berlin Sitz.", 1(1917) 142-152.

pronounced against the first, yet very bashful, suggestions concerning the dynamic character of the Universe very decidedly[3].

These suggestions, however, were being drawn out and developed. It was taking place first in connection with W. de Sitter's model and Alexander Friedman's solutions of gravitational field equations[4]. It was just Friedman, as the first one in the history of cosmology, to admit clearly the idea that the Universe did not have to be a building with an unchangeable architecture but it could be a process in itself.

At the beginning this view was expressed very guardedly, only as a mathematical possibility (as an uncontradictory idea) but it was also an idea which initiated the very important process of replacing and refuting the view of the Universe as being static. This process was crowned with the acceptance of a dynamic vision of the Universe at last. It did not, though, continue – like each revolution-meekly and in an univocally directed manner. It swarmed with different kinds of clashes and dramatic situations and therefore it had a very rich and rather long history. It seems that the discovery of the microwave background radiation in 1965 was the best essential finding that finally removed all the fundamental objections to the dynamic vision of the Universe, and in turn forced the rejection of the static theory. This does not, however, mean that today there are no discussions on this subject among cosmologists, although the majority of scientists are convinced of the expansion and evolution of the Universe. This conviction has become a strong element of the modern knowledge of the Cosmos.

A very important contribution to this process was put forth by a Belgian professor, Georges Lemaître, who should be considered as one of the main founders of the dynamic view of the Universe. So the aim of this paper is to present, as well as possible, the essence of his contribution. As a result, these considerations will concentrate both on Lemaître's genesis of the dynamic view of the Universe and on the essential aspects of his contribution to this idea.

Consequently, the most important value of this kind of analyses is the attempt to reconstruct the formation and acceptance of the idea of the dynamic Universe in the scientific community as illustrated by one of its founders. After considering this point one is better able to examine the historical context of the theory of the expanding Universe and therefore the theory itself can be better understood.

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[3] A. Einstein, *Kritisches zu einer von Hrn. de Sitter gegebenen Lösung der Gravitationsgleichungen*, „Berlin Sitz.", 1(1918) 270-272; *Bemerkung zu der Arbeit von A. Friedmann: Über die Krümmung des Raumes*, „ZS.Phys.", 11(1922) 326; G. Lemaître, *Rencontres avec A. Einstein*, „Rev.Ques.Sci.", Janvier 1958, p. 130.

[4] A. Friedman, *Über die Krümmung des Raumes*, „ZS.Phys.", 10(1922) 377-386; *Über die Möglichkeit einer Welt mit konstanter negativer Krümmung des Raumes*, „ZS.Phys.", 21(1924) 326-332.

On the other hand, such attempts can also be deemed valuable to the philosophy of science. Concentrating upon the real example of the scientific revolution, that is upon the transition from a static to a dynamic view of the Universe, these attempts offer to philosophical analyses both the starting point for some reflections on science in general, particularly on its development and the materials to verification of already existing theories. Therefore, these considerations meet the postulates of the popular trend in contemporary philosophy of science, called „historism". These postulates are defined as demanding all philosophical reflections on the science to be carried out in close connection with real practice of science and not in a separation of all that happens in the science.

At last these analyses are the expression of the hommage paid to the scientist who took an important part in the formation of the idea of a dynamic view of the Universe, who exerted a great influence on the directions of development of that idea, and who devoted the main part of his very laborious life to this idea in spite of numerous difficulties.

II. LEMAÎTRE'S GENESIS OF THE IDEA OF THE EXPANDING UNIVERSE

The idea of dynamic vision of the Universe appeared in Lemaître's mentality in close connection with his cosmological interests. It is, however, difficult to say if those cosmological interests were consequences of Lemaître's previous studies of Einstein's Theory of Relativity or if they appeared independently of them. But it is obvious that without knowing this theory it is impossible to practise relativistic cosmology. Therefore, regardless of reasons, Lemaître's cosmological works had to be preceded by his reliable study of gravitational theory.

In the Archive of Lemaître's works at the Catholic University of Louvain-la-Neuve (Belgium) there are two notes by Lemaître on the Theory of Relativity. One of them entitled „La Physique d'Einstein", bearing the date 31 May 1922 contains a very clear exposition of the Special and General Theory of Relativity. The second one, bearing no date, was entitled „Theorie de la Relativité". They were made by Lemaître to further enhance the Relativity Theory. The date on one of them, 31 May 1922, points out that the author was deeply interested in Einstein's theories long before his first cosmological publications. It took place at the time when he was a theology student attending seminary. It was really a period of extreme fame for the Relativity Theory and of its founder throughout the world. As a result, Lemaître had to hear about it all the more so, in 1920 Einstein delivered a lecture on the relativistic theory in the neighbouring town of Leyda in Holland[5]. According to known material on

[5] A. Einstein, *Äther und Relativitätstheorie: Rede gehalten am 5. Mai 1920 an der Reichs-Universität zu Leiden*, Berlin 1920.

Lemaître's life he learned about the relativistic physics from the genuine works alone and he acquired also tensor calculus which was not well known at the Louvain University at that time [6]. Next he was given the opportunity to increase his relativistic interests during his stay in Cambridge in 1924, where he was sent as the prizewinner of the competition for a further education. He had possibilities to work with Arthur Stanley Eddington who was reputed to be one of the best specialist in Relativity at that time. Besides the Relativity Theory, Eddington was also of great importance in contemporary relativistic cosmology. Because of this Lemaître could become acquainted with the most frequently discussed problems in this field[7]. It would seem that while at Cambridge Lemaître committed himself in the problems of cosmology and continued to do since that time.

Because of ignorance of Friedman's solutions only two cosmological models were considered: Einstein's original model containing uniformly distributed dust-like matter and de Sitter's model containing no matter. Both of them were believed to be static but de Sitter's model stirred many different controversies. First of all, de Sitter's solution opposed to the Mach-Einstein principle which was considered at that time to be one of the most fundamental principles of the General Theory of Relativity and which played an important part in the construction both of the theory and the Einstein's static model. If it was possible for the curved space-time to exist without the matter content then the General Theory of Relativity did not realize the Mach-Einstein principle and inertia was not only consequence of the influence of the distant masses to a body[8].

Next de Sitter's model appeared as an interesting mathematical case. The first point of this case was showing space-time as a four-dimensional surface of the hyper-pseudosphere with the constant, apparent radius embedded in five-dimensional Euclidean space. In addition, the metric proposed by de Sitter is divided into closed instant spaces (with constant, positive curvature) and time which, in opposition to Einstein's – is not represented by straight but by curved lines. What is more, the transformations of this line-element to the new coordinate system showed that it could be non-static. These were the reasons why de Sitter's model was subject to special mathematical analyses[9].

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[6] Ch. Manneback, *Hommage a la Memoire de Mgr Georges Lemaître. Allocution prononcée devant la Classe des Sciences de l'Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique, le 2 juillet 1966 par le Secrétaire perpétuel*, pp. 1-6.

[7] Ch. Manneback, *L'expansion de l'univers et les théories du Professeur Lemaître*, „Union des Ingénieurs Sortis des Ecoles Speciales de Louvain 1934, 1-er Bulletin Technique", Numero spécial, p. 45-46.

[8] North, *The Measure of the Universe*, pp. 87-92.

[9] M. Heller, *Ewolucja kosmosu i kosmologii*, Warszawa 1983, pp. 27-32; North, *The Measure of the Universe*, pp. 106-109.

At last this model was interesting to astronomers. Though it stood in opposition to common observations showing that the real world is filled with matter but on the other hand until finding dynamic solutions of gravitational field equations it was the only one that gave some theoretical explanations of the observed (since Slipher's times, 1912) displacements towards red in the spectrum of long-distant galaxies[10]. One could think that Eddington, who was probably the first to realize the astronomical significance of de Sitter's world, suggested a subject of study in this domain to Lemaître. A short paper on de Sitter's model prepared by Lemaître just at Cambridge and published later in the United States seemed to be the result od Eddington's suggestions[11]. The most important problem which appeared in the context of de Sitter's world was the question of readshift observed in the spectra of distant galaxies. Lemaître noticed some possibilities to explore this field. Based upon red-shift measurements he pursued this interest in extra-galactic observations carried in the United States and eventually went there supported by C.R.B. Educational Foundation. He visited the Mt Wilson Observatory where in 1923-25 Edwin Powell Hubble identified Cepheids in the Great Nebula of Andromeda and thereby determining the distance to them. In 1925 at the Washington Academy he could listen to Hubble's lecture on the observational data of the red-shifts and of the calculations of the distances to the galaxies. Next, Lemaître spent time in Flagstaff (Arizona), where Vesto M. Slipher of the Lowell Observatory, for the first time, discovered the spectral displacement of many galaxies. For a longer time he stayed at the Harvard College Observatory and at the Massachusetts Institute of Technology which he called his second Alma Mater. Harlow Schapley was the director of the Astronomical Observatory and Lemaître had a lot of opportunities to discuss different astronomical problems with him. He himself acknowledged that just there, in the United States, his scientific orientation concerning cosmology was specified very clearly[12]. Having extensive knowledge about the relativistic theory and theoretical cosmology, he came across also the newest extragalactic investigations and realized their great importance to relativistic cosmology. Without them a lot of cosmological inquiries would remain only in the sphere of imaginations and myths. While in the United States Lemaître's great career in cosmology began and particularly there, that idea of the expanding Universe assumed the explicit shapes.

This idea, however, originated very slowly and with great effort in Lemaître's mind. It was closely connected with his cosmological interests and it appeared both on theoretical and observational levels.

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[10] North, *The Measure of the Universe*, pp. 92-104.

[11] G. Lemaître, *Note on de Sitter's Universe*, „Harvard College Observatory", March 1925, p. 37-41.

[12] G. Lemaître, *Réponse de M. le professeur Abbé G. Lemaître*, „Union des Ingénieurs", pp. 39-43.

Lemaîtrè saw plainly the advantages and disadvantages of Einstein's and de Sitter's models. The first model contained matter but could not explain the numerous red-shifts without auxiliary hypothesis, whilst the second was devoid of matter but pointed out a possible dynamic character of the Universe[13].

From these two theories Lemaître felt something had to be done and while studing at Cambridge he completed his first cosmological paper entitled „Note on de Sitter's Universe" which subjected de Sitter's solution to a mathematical analyses. He noticed that although de Sitter's space-time as whole is homogeneous, nevertheless, its partition into space and time disturbs this homogeneity. This meant that instant spaces had one distingushing point in the coordinates used by the Sitter to describe his world. This point can be interpreted like a center of the Universe. So Lemaître tried to remove this difficulty by introducing other coordinates in which the instant spaces would be truly homogeneous. He found such a coordinate system in which space-time splits into universal cosmic time and instant spaces without distinguished points in the natural manner. Nothing, however, was without its costs or consequences. The space-time of de Sitter's world appeared to have two unexpected properties in the new coordinates, which astonished Lemaître. Firstly, the instant spaces were non-static and secondly they had no curvature, they were flat. This introduced evolution to de Sitter's world which was a great difference compared with Einstein's model.

Then Lemaître showed that it could be easy to calculate the spectrum-shift formula using the new coordinates. He interpreted this displacement as the Doppler effect. This meant that every two test particles put to de Sitter's model would tend to scatter and consequently this model appeared to be expanding. Commenting on this fact Lemaître quoted Eddington's words that the non--static property of de Sitter's world was in favour of de Sitter's theory rather than against it, all the more so as it gave a possible interpretation of the receding motion of galaxies[14].

Conclusions deduced from the analyses of de Sitter's model were first and mainly theoretical previsions of the possible existence of the dynamic Universe. These previsions were next developed and intensified by Lemaître's introduction into the observation of the world of galaxies which were carried out in the United States. Learning of Hubble's lecture was the turning-point for him. Having good theoretical preparation in cosmology, Lemaître noticed the value of Hubble's observations to the idea of an expanding Universe. According to Professor Godart's report it was during this lecture that the idea of an expanding Universe became very clear to Lemaître[15]. He himself was not only con-

[13] G. Lemaître, *Un univers homogène de masse constante et de rayon croissant, rendant compte de la vitesse radiale des nébuleuses extra-galactiques*, „Ann.Soc.Sci.Brux.", 47A(1927) 49-51.

[14] Lemaître, *Note on de Sitter's Universe*, pp. 40-41.

[15] Private information from Professor Godart.

vinced of it but also thought of the realization of that idea, that is of construction of an expanding model.

The idea, as always happens with ideas of this kind, was very simple. One ought to have found such a solution of Einstein's field equations which would have only the advantages of both known models, that is, the new model would contain matter and would expand[16].

Lemaître linked his considerations about such a construction strictly with observational investigations of the Universe. Therefore, the title of his paper „A Homogeneus Universe of Constant Mass and Increasing Radius Accounting for the Radial Velocity of Extragalactic Nebulae" is significant.

This article was published in 1927 in a local Belgian journal „Annales de la Société Scientifique de Bruxelles" and for three years remained unnoticed by the majority of the scientific world, at last Eddington, working on the problem of instability of Einstein's static model, came across it. Having studied this paper Eddington was the first to appreciate its value. Later on he managed to publish its English translation in the better known astronomical journal „Monthly Notices of the Royal Astronomical Society"[17].

This way, the idea of a dynamic Universe, became better known and soon it met approbation.

III. THE MAIN POINTS OF THE LEMAÎTRE'S CONTRIBUTION

Before Lemaître's fundamental work the situation in cosmology was very difficult. Friedman's solutions were still unknown. The new measurements of the red-shifts for remote galaxies spectrum were provided by astronomers. Many of them began to realize that the explanation of the spectral displacements given by de Sitter's theory was not precise. De Sitter's world was empty, there was not the recession of galaxies and only the space expanded. In this context a need for a total re-evaluation in cosmology became evident. Cosmologists started to look for a new theory which would not only solve these problems but also point out further development in cosmology[18].

These were precisely Lemaître's suggestions, which appeared to meet these expectations half-way. Since the time of Hubble's famous lecture at the Washington Academy, Lemaître was working very hard to realize his purpose. His intention was to find a model that would be an intermediate between Einstein's static universe and the empty world of de Sitter. This meant that the required

[16] Lemaître, *Un univers homogène de masse constante*, p. 51.

[17] G. Lemaître, *A Homogeneous Universe of Constant Mass and Increasing Radius acounting for the Radial Velocity of Extra-galactic Nebulae*, „Monthly Not.Roy.Astron.Soc.", 91(1931) 483-490.

[18] North, *The Measure of the Universe*, pp. 70-109.

model had to have both material content and definite spectral displacement. Additionally, this model should begin from Einstein's model and end its expansion in the empty world of de Sitter. So, these two models should be the initial and final states of a single more general model[19].

Wishing to achieve this purpose Lemaître proceeded in the way very similar to Friedman's. From Einstein's field equations he deduced differential equations equivalent to Friedman's, provided the pressure term is ignored. He did it, however, quite independently of Friedman's works, which at the time were completely unknown to him. He considered a case of constant positive space curvature, which produced an infinite number of different possible models[20]. In Lemaître's Archive in Louvain-la-Neuve there are some notes in his handwriting connected with his 1927 paper and two diagrams presenting all these possible solutions for the case of constant positive space curvature. This means that Lemaître knew all these possible solutions[21]. Being, however, characterized by the physical style of thinking he wanted to study only the real Universe and not a mathematical structure of the received differential equations. Therefore, he chose one concrete model from other ones, thinking that it described the real Universe in the best way. In his opinion other models could not be treated seriously as they provided a too short time-scale as compared to that of stellar evolution[22].

Lemaître chose the required model by adjusting constants of integration to their values in Einstein's static universe. Consequently, he obtained rather special solution, known afterwards at the Eddington-Lemaître world model. This model describes the expanding Universe with non-vanishing matter density. The so called radius of the Universe increases steadily as time increases. As time goes to minus infinity, the radius approaches asymptotically the static universe of Einstein. On the contrary, as time goes to plus infinity, the model approaches de Sitter's world. And so, this model is asymptotic in the past to Einstein's universe and in the future to de Sitter's world[23].

Wanting to know if this model describes the real Universe Lemaître had to compare it with extra-galactic observations. He became familiar with them during his stay in the United States. Therefore, he derived from his model the formula for Doppler-effect and noticed that this formula explained the apparent red-shifts in the galaxy spectra. Next in the case when light sources are near

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[19] W.H. McCrea, *Cosmology to-day. Inaugural lecture of the Chaire Georges Lemaître*, „Rev.Ques.Sci.", Avril 1970, p. 224.

[20] Lemaître, *Un univers homogène de masse constante*, pp. 51-54.

[21] M. Heller, *Questions to infallible oracle*, w: *Physics of the Expanding Universe*, ed.by M. Demiański, (Lecture Notes in Physics), 109, 1979, pp. 201-204.

[22] Lemaître, *Un univers homogène de masse constante*, p. 58.

[23] O. Godart, *Comments on Lemaître Cosmological Models*, „Acta Cosmologica", 4(1976) 50-51.

[24] Lemaître, *Un univers homogène de masse constante*, p. 58.

enough, he obtained the very important relationship. According to this relationship the velocity of galaxy recession deduced from the Doppler interpretation of its red-shift, should be proportional to its distances. This was one of the first theoretical predictions of the so called „Hubble's law", published by Hubble two years later. Having such theoretical consequences Lemaître compared them with 43 redshift measurements made by Strömberg and 42 made by Hubble himself. The general conclusion was: „The receding velocities of extra-galactic nebulae are a cosmic effect of the expansion of the universe"[24], that is to say, the whole astronomical Universe is expanding.

Lemaître favoured this model because it pushed back the start of the expansion into the infinite past. In this way the problem of the age of Universe could be solved. Other models gave a too short of time compared with the time of stellar evolution[25].

This model was also favoured by Eddington. He studied the problem of instability of Einstein's model and noticed that it was not as stable as it had been considered before[26]. The initial small disturbance of Einstein's model was enough to make the Universe expand. That was precisely Lemaître's suggestion. Eddington accepted this model and also supported it very strongly for philosophical and aesthetical reasons. He did not like the violent beginning and felt that only the model with slow „aesthetical" transition from equilibrium to expansion was worth considering[27]. Therefore, this model was referred to afterwards as the Eddington-Lemaître world model.

Now we can say that the appearance of the Eddington-Lemaître model was the first essential step towards the formation of the dynamic view of the Universe. Admittedly, Friedman's solutions that had appeared earlier were passed by because they were not known and therefore they could not play a due role in this very early period of the formation of dynamic picture of the Universe. Besides this, Friedman's solutions were only mathematical discussions, without, however, any connection with the known observational data. Lemaître, instead, proposed one concrete model which was constructed in strict connection with observations. This meant that for the first time relativistic cosmology gained some relationships with extra-galactic observations more clearly and successfully. It was a great achievement. Cosmology could be considered as an empirical science. On the other hand, the astronomers' world stopped being only a collection of galaxies and became the system of galaxies.

In regard to the acceptance of this dynamic view among scientists' two reasons played an important role. Firstly, Lemaître's paper was easy to attain af-

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[25] P.A.M. Dirac, *The scientific work of Georges Lemaître*, „Commentarii, Pontificia Academia Scientiarum", 2(1968), N. 11, pp.9-10.

[26] A.S. Eddington, *On the Instability of Einstein's Spherical World*, „Monthly Not.Roy. Astron.Soc.", 90(1930) 668-678.

[27] A.S. Eddington, *The Expansion of the Universe*, Cambridge 1933.

ter its republishing in a well known English journal. Secondly, this republishing coincided with a very important article by Hubble in which the main results of Hubble's observations were contained[28]. Lemaître's article gave some theoretical explanation and support to these results.

And so, thanks to Lemaître's suggestions, the transition from the static picture of the Universe to its dynamic view was done. An essential turn in human outlook took place. The Universe appeared not as a fixed one but as a continuously expanding reality. Obviously, the appearence of Lemaître's work did not mean that the idea of the expanding Universe would be accepted automatically by all, in the version proposed by the Belgian scientist. He himself changed it a lot, but the main step was settled. The long period of development and growth of the idea was begun. Also Lemaître contributed greatly to that process.

First of all, looking from today's point of view, the idea of a dynamic Universe would not have been complete if it had not contained the thought about the beginning of the Universe, i.e. about the initial singularity[29].

Lemaître was the first scientist who connected an initial singularity with the idea of an expanding Universe. This was great contribution to the formation of the idea of the dynamic Universe. Although Einstein[30] and Eddington[31] opposed the idea of a initial singularity, Lemaître was for the model which started its expansion from a certain distinguishable moment in finite past. He thought such a model described the real Universe the best and he was right. The model with an initial singularity is commonly accepted by contemporary cosmology[32].

There were several reasons why Lemaître changed his attitude[33]. As it is known that at first he had accepted the model according to which the Universe started off in the infinite past from Einstein's world. This model, however, posed some new very important questions related to character its revolutionary character. First question was, what caused the Universe to expand after remaining in equilibrium for such a long time. The only rational answer to this question seemed to be by the formation of condensations. Indeed, mathematical computation pointed out that any general process of condensation, occurring in the Universe where the kinetic energy does not vanish, must induce expansion. But soon it proved that time which was required to formation the

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[28] E.P. Hubble, A Relation between Distance and Radial Velocity among Extra-galactic Nebulae, „P.N.A.S.", 15(1929) 168-173.

[29] Ch. Misner, K.S. Thorne, J.A. Wheeler, *Gravitation*, San Francisco 1973.

[30] Lemaître, *Recontres avec A. Einstein*, p. 130.

[31] A.S. Eddington, *The Expansion of the Universe*, Cambridge 1933.

[32] J. Silk, *The Big Bang. The Creation and Evolution of the Universe*, San Francisco 1980.

[33] See for example: O. Godart, J. Turek, *Le développement de l'hypothèse de l'atome primitif*, „Rev.Ques.Sci.", Juillet 1982, pp. 150-155.

condensation was too long as compared with the duration of evolution. So it was no longer possible to consider the formation of the condensations as the cause of the expansion[34]. In addition, it was difficult for one to understand how, from a physical point of view, the Universe could have remained near equilibrium for infinite time. A minimal change of a distribution of matter in such a state would break the equilibrium relatively quickly[35].

Lemaître also noticed that it was impossible to join the old Kant-Laplace cosmogony with contemporary ideas on the subject. There were too many discrepancies between them, particularly concerning the time-scale, for such a connection to be possible. The cosmology of the past was the slow one. This theory demanded many tens of billions of years to form the present structures of the world, whereas, the expansion of the Universe was estimated at only several billion years.

Therefore, the Eddington-Lemaître model corresponding by the primordial equilibrium to Kant-Laplace cosmogony was no longer useful. Consequently, the author realized that the best way to solve all these difficulties would be withdrawing this model from consideration[36]. He was encouraged in such decision by some purely physical reasons.

One can notice a natural tendency of matter to break up into smaller and smaller particles. This can be observed for example, in energy, photons, radioactive elements, etc. Then, this seems to indicate that evolution took place from the simple to the composite and not from the diffuse to the condensed[37]. Thus Lemaître began to look for another type of expanding models. The best ones which responded also to the physical suggestions, were models with an initial singularity. Lemaître decided to accept them because there was no alternative. On the other hand there were also no possibilities of removing singular points from these models. They appeared in the solutions of gravitational equations not as the consequence of the symmetry assumption but as the result of very general properties of space-time.

Lemaître chose a special model which was later called by his name. This was the solution of the Friedman equation for the case of constant positive space curvature with a cosmological constant (λ) slighty greater than Einstein's original value. Three periods of expansion were the most characteristic of this model. This expansion started from an initial singularity very rapidly. So the first stage of expansion consisted of rapid movement. In the course of time, however, the rate of expansion slowed down because of gravitational forces. The model was passing slowly through Einstein's state. This state has come to be known as the „stagnation period". The matter density was smaller than the cri-

[34] G. Lemaître, *L'expansion de l'espace*, „Rev.Ques.Sci.", November 1931, p. 403.
[35] G. Lemaître, *L'Univers en Expansion*, „Rev.Ques.Sci.", May 1935, p. 367.
[36] Godart, Turek, *Le développement de l'hypothèse de l'atome primitif*, p. 154.
[37] Lemaître, *L'expansion de l'espace*, p. 405.

tical value so the gravitational forces could not reverse the expansion of the Universe to a process of contraction[38]. This was a state similar to the dynamic equilibrium from which the Eddington-Lemaître model took its expansion. So Lemaître did not abondon the idea of the equilibrium but only introduced it in a different period of expansion. This step appeared to be very useful to discuss some problems which had arisen in cosmology. Particularly, according to Lemaître, it gave forth an opportunity of solving the very serious problem of the Universe's age. He noticed that taking λ values sufficiently close to Einstein's critical value, the model would linger as long as it may be required in the vicinity of the Einstein state. Thus by this simple device one could produce a model of the Universe having apparently as long a life as we need. Besides this, „the stagnation period" played a very important role in Lemaître's theory of the formation of the present structures of the Universe. The stagnation period gave forth the possibilities of local fluctuations to initiate the formation of the condensations from which galaxies and clusters of galaxies evolved. And so, the matter was agglomerated in certain places, while the Universe in its entirely, would resume its accelerated expansion. In this way, the Universe entered the third phase of expansion, which will be continued infinitly[39].

We can say, that the acceptance of the model with the initial singularity was an important step forward in the formation of the dynamic view of the Universe. Lemaître was the first, consequently, who introduced the initial singularity and tried to give a physical interpretation to it. His desire was to construct a new cosmological theory which, resulting from ideally simple conditions, could describe the whole evolution of the Universe from the very beginning to its present state in all its complexity. He himself called the theory the Primeval Atom Hypothesis[40]. Constructing the Hypothesis, Lemaître started with a description of an initial singularity. He applied to this theory both the astronomical observations and achievements of quantum physics of those days. The astronomical data mentioned the recession of the galaxies. And so, as we go back in time, the galaxies should have approached one another and the matter should have had a higher and higher temperature, density and pressure. Consequently, all the structures of the Universe should have been crushed. The radius of the Universe would have moved toward zero and the temperature, density, and pressure – to infinity[41]. In order to describe and imagine such a state of matter Lemaître was assisted by quantum physics. He noticed that the thermodynamic principles, from the point of view of quantum theory, might be stated as follows: „(1) Energy of constant total amount is distributed in discre-

[38] G. Lemaître, *L'hypothese de l'atome primitif*, „Actes de la Société Helvétiques des Sciences Naturelles", 1945, p. 13.

[39] Lemaître, *L'Univers en Expansion*, pp. 369-370.

[40] G. Lemaître, *L'expansion de l'espace*, p. 409.

[41] G. Lemaître, *L'Univers en expansion*, „Ann.Soc.Sci.Brux.", 62(1933), ser.A,p.84.

te quanta. (2) The number of distinct quanta is ever increasing". Therefore, he concluded „if we go back in the course of time, we must find fewer and fewer quanta until we find all the energy of the Universe packed in a few or even in a unique quantum"[42].

The observation of natural desintegration of radioactive elements led Lemaître to the same conclusion. In the beginning, there had been a single atom whose radioactive desintegration created, through a series of succesive splittings, the less stable atoms than those which exist today[43].

Lemaître used a lot of different terms borrowed from the quantum physics to denominate the primordial state of the Universe. At last the „primeval atom" became generally accepted. It was not, however, used in purely physical but rather in the ancient Greek sense of the word. It contained the entire energy of the Universe which was condensed into a few or even in a one packet. Consequently, it had to be the state of minimum entropy[44].

The Primeval Atom was extremely unstable. From the time of its existance it burst into smaller and smaller particles. This desintegration derived the history of the Universe. The Primeval Atom Hypothesis was to describe this history, i.e. to explain not only the formation of clusters of galaxies, galaxies, stars and planets but also the existence of elements[45].

Most of these explanations and statements have lost their significance today because of further developments in cosmological theories. Nevertheless, the general ideas of the Primeval Atom Hypothesis concerning the evolution and expansion of the Universe have remained unchanged. They can be found in the so called standard model of the Universe, commonly accepted by contemporary cosmology. The Hypothesis should be considered as an important link in the development of relativistic cosmology. It contributed a great deal to the acceptance and diffusion of the idea of the expanding Universe. The model taking its expansion from an initial singularity was its natural background. Within the scheme of the Primeval Atom Hypothesis the fusion of both ideas of expansion and evolution of the Universe took place for the first time very clearly. The expansion of the Universe was the main condition of its evolution. It would be difficult for one to think about evolution without previously accepting the expansion of the Universe. The Primeval Atom Hypothesis was a physical expression of the idea of the expanding Universe. The idea of expansion stands at the base of such problems as the beginning of the Universe, nucleosynthesis, the age of the Universe, etc.

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[42] G. Lemaître, *The Beginning of the World from the Point of View of Quantum Theory*, „Nature", May 9(1931) 706.

[43] Lemaître, *L'expansion de l'espace*, pp. 403-404.

[44] G. Lemaître, *The Primaeval Atom Hypothesis and the Problem of the Clusters of Galaxies*, w: *La Structure et l'Evolution de l'Univers, XI Conseil de Physique*, Bruxelles 1958, p.6.

[45] Lemaître, *L'hypothèse de l'atome primitif*, pp. 13-19.

There is still one more important aspect of the connection of the Primeval Atom Hypothesis with the idea of the expanding Universe. Lemaître looked for the possibility of some kind of verification of his theory. If he could deduce some empirical implications from the Hypothesis and if these implications agreed with observations he would be able to verify not only the Hypothesis but also the idea of expansion of the Universe from an initial singularity. Looking for such possibilities, Lemaître was intrigued by the very intense energy of cosmic radiation. Just the desire to point out the sources of this energy, was a strong motive to construct the Primeval Atom Hypothesis. According to this theory the cosmic rays were glimpsed of the primeval firework of the Primeval Atom, coming to us after their long journey through free space. So Lemaître hoped those rays could be one of the main empirical tests of his Primeval Atom Hypothesis. He looked therefore, for a greater understanding of their structure. He was right with one exception: cosmic rays should be replaced by the microwave background radiation discovered in 1965. Two weeks before his death Lemaître learned about this discovery and was happy that his expectations were correct. The idea of the expanding Universe has acquired the experimental support and has become one of the most important elements of the human outlook.

IV. CONCLUSIONS

The analyses of above have shown that Lemaître's contribution to the formation of a dynamic view of the Universe was extremely valuable and important.

Admittedly, he belongs to the small group of the co-founders of the idea. He never wanted to construct only mathematical abstractions about the Universe but to form a very concrete theory. Such an attitude demanded the connections of cosmological considerations with the observed data. From this union of theoretical and empirical approaches to cosmology the idea of an expanding Universe arose. The Belgian Professor was one of the first who suggested this idea very clearly and plainly. His 1927 paper was the turning-point in the human understanding of the Universe. The long period of transition from a static to a dynamic view of the Universe was started. Lemaître also played a great part in that process. He deserves the credit for the acceptance of an initial singularity as a starting point for the expansion of the Universe. Today, an initial singularity is something obvious, commonly accepted in cosmology but in Lemaître's time it was not so. The majority of cosmologists did not want to accept a model with singularity. So, the author had to have a lot of courage to oppose such authorities as Einstein and Eddington. He not only accepted the model with an initial singularity but also tried to give it a physical interpretation. Consequently, the Primeval Atom Hypothesis was established. Its purpose was to describe satisfactorily the whole evolution of the Universe from the initial moment to its present structures.

Obviously, it is very difficult to expect that Lemaître's suggestions could be acceptable wholly by present cosmologists. Nevertheless, his general ideas remained intact and can be found in the so called standard model. With the discovery of the microwave background radiation in 1965 the idea of dynamic view of the Universe acquired the experimental support. Lemaître's expectations were fulfilled. The Universe appeared as a constantly changing reality.

The above considerations also point out the factors which took part in the formation and acceptation of the dynamic picture of the Universe. This idea arose from the efficient utilization of both theoretical analyses and the observational data. It successfully happened that these research-works were done nearly at the same time. Consequently, the theoretical analyses found very quickly an empirical support and thanks to this they could be accepted more easily. On the other hand observational data gained a deeper meaning and theoretical explanation.

Science, however, cannot be practiced without people. Therefore, its development depends very strongly on the scientists and on the conditions in which they work. One can notice this dependance very clearly in the case of idea of the expanding Universe. It is difficult to say how this idea would have been developed without Lemaître, but it really owes a great deal to Lemaître's immense intuition and scientific imagination. They helped him to detect a new approach to cosmology and consequently, they helped him to construct a new cosmological theory.

Besides these, the circumstances in which Lemaître worked were of great importance to this scientific achievements. He was successful to acquaint with the newest cosmological research as well as to meet great scientific authorities in his life (Eddington, Einstein, Hubble etc.). They not only introduced him into the scientific community but also supported him in his efforts to construct the theory of expanding Universe.

Well, both scientific and non-scientific factors exerted an influence on the formation of dynamic view of the Universe.

WKŁAD JERZEGO LEMAITRE'A W KSZTAŁTOWANIE SIĘ DYNAMICZNEJ WIZJI WSZECHŚWIATA

Streszczenie

Przejście od statycznej do dynamicznej wizji Wszechświata uważane jest za jedną z największych, równą kopernikowskiej, rewolucji naukowych ostatnich lat.

Ważny wkład w proces kształtowania się tej rewolucji wniósł znany belgijski kosmolog, ks. J. Lemaître. Przede wszystkim znalazł on, zupełnie niezależnie od A. Friedmana, niestatyczne rozwiązania Einsteinowskich równań pola i jako pierwszy powiązał je z ówczesnymi obserwacjami astronomicznymi. Efektem tego był tzw. model Eddingtona-Lemaître'a. Wkrótce Lemaître zaproponował model z tzw. osobliwością początkową, co stanowiło następny krok w procesie kształtowania się dynamicznej wizji Wszechświata. Dalszym przejawem tego wkładu była próba fizycznej interpretacji osobliwości i zbudowanie w ramach modelu ekspandującego ogólnej teorii ewolucji Kosmosu. Dało to w efekcie znaną Hipotezę Atomu Pierwotnego, której pewne idee odnaleźć można w tzw. standardowym modelu Wszechświata.

Oprócz powyższych zasług Lemaître'a artykuł ukazuje również genezę idei ekspandującego wszechświata i czynniki, które wpłynęły na jej akceptację w środowisku uczonych.

Ważną rolę odegrały tu indywidualne cechy belgijskiego kosmologa, a przede wszystkim umiejętność wiązania badań teoretycznych z obserwacyjnymi i wyciąganie stąd właściwych wniosków. Nie bez znaczenia były również osobiste kontakty twórcy Hipotezy Atomu Pierwotnego zarówno z wiodącymi ośrodkami naukowymi, jak i znanymi uczonymi. Pewien wpływ miała też wyraźna współzależność czasowa w badaniach teoretycznych i obserwacyjnych kosmologii; ostatnie domagały się wyjaśnienia i dlatego propozycje teoretyczne budziły zainteresowanie.

Widzimy więc, że proces odchodzenia od statycznej wizji Wszechświata do jego obrazu dynamicznego przebiegał zarówno pod wpływem czynników wyraźnie naukowych, jak i pozanaukowych, związanych ze środowiskiem uczonych oraz czasową współzależnością badań.