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The Lego of the Universe: How we Construct the Universe from Elementary Particles?

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Editorial

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INTRODUCTION

We know that everything is built of smaller, more elementary pieces. The deeper we put our glance in the surrounding bodies, the more complicated their structure appears. If we take microscope, elementary parts of body become complex and the next level of elementarity comes. Starting from antiquity there was a challenge to reduce the set of fundamental substances, of which everything around us is constructed. For long time the idea of atom (indestructible) was considered as the final step in this way to final elements of Nature, and this idea was realized in chemistry, putting the constituents of all the existing molecules in the Mendeleev table of chemical elements.

However, atoms turn out to be complex too – they consist of nuclei and electrons and nuclei in their turn consist of protons and neutrons – barons, giving the dominant contribution into the mass of the atomic matter. Disintegration of atom and then nucleus gave rise to the current understanding of elementary particles. They are not indestructible unchangeable eternal species, recombined in various complex structures, but they are the entities that can transform one to other and instead of strict balance of particle recombination come strict laws, regulating their transformations. These laws reflect the symmetry between different types of particles. This symmetry implies the existence of elementary acts of particle transitions, in which the initial particle is annihilated, and the final state particle is created owing to emission or absorption of a quantum of a field, mediating fundamental particle interaction. The difference between different types of particle transformations is explained by mechanisms of symmetry breaking.

It lead to the modern picture of the so called Standard model of elementary particle physics that finds strong support in the experiments at particle accelerators and colliders. The last missed element in the set of fundamental particles of the Standard model (SM), the Higgs boson was discovered at the Large Hadron Collider (LHC) in 2012.

However it is not the end of discoveries in particle physics, since the wide field of physics Beyond the Standard model is badly needed and waits for its exploration.

Theoretical and practical need to extend the SM follows from its internal problems, some of which can be solved by super symmetry – symmetry between bosons and fermions. Since we do not observe super symmetry in the mass spectra of known fermions and bosons, then it must be broken, and the search for super symmetric partners heavier than the corresponding particles is one of the greatest challenges for the Large Hadron Collider and/or the next generation of accelerators. The idea of unifying all the fundamental forces of Nature is the

aesthetically appealing reason for the extension of the SM. The similarity of the description of the fundamental particle interactions (electromagnetism, strong and weak interactions), achieved in the SM, is embedded deeply in a grand unified theory (GUT), which extends the fundamental symmetry of elementary particles.

By placing the set of known particles in such theory, we see that there remain 'white spots' which should be occupied to complete it.

The wider the theory, the larger is the number of additional particles and fields, corresponding to the total symmetry. These particles and fields correspond to the 'hidden sector' of

the relevant theory, since they are hidden from direct experimental verification or because of their large mass, or because of the extremely weak interaction with the known particles.

In both cases, the (super-weak interaction, or very super-large mass) verification of the predictions requires the use of indirect methods. That is why the expanding Universe, as a possible source of information about elementary particles, attracts the most attention of people involved in elementary particle physics. Modern cosmology is based on two observational facts. On the fact that the Universe is expanding, and that the modern Universe is filled with the thermal background of electromagnetic radiation. Combining these facts leads to the ideas of Big Bang expanding Universe. Big Bang theory leads to very high temperatures at the very early stages of expansion. We can never build an accelerator of elementary particles to energies of the GUT which are naturally realized in the early stages of cosmological evolution. Thus, the internal development of particle physics leads to the theory of a hot expanding Universe, called Big Bang Universe, as a natural landfill of its fundamental ideas.

However, to resolve the quantitative inconsistencies, which at a deeper examination became more pronounced, it has been necessary to add new fundamental elements to the basics of its theoretical constructions. The theory of the Big Bang Universe is now supplemented by at least four additional elements – inflation, baryosynthesis, non-baryonic dark matter and dark energy, based on physical laws predicted by the theory of elementary particles which, however, have not been experimentally verified.

The inflation gives the principal answer for the questions why is the Universe expanding? Why the expansion makes the Universe so homogeneous and isotropic? and Why the evolution in causally disconnected regions is identical? It suggests that in the past there was a phase of superluminal (in the simplest case of exponential) expansion in the early Universe.

This stage could not form if matter, radiation or relativistic plasma was dominant but it could, under certain conditions, form under the effect of various cosmological implications of the theory of elementary particles,

The question: Why does the Universe not contain an equal amount of matter and antimatter? finds its answer in the process of baryosynthesis, linking this observed baryon asymmetry of the Universe with the physical mechanism of generation of an excess of matter in the early Universe.

To explain the difference in the amount of baryonic matter and the total amount of matter in the Universe the dark matter is needed, the physical basis of which relate to the hidden sector of particle physics.

There are many different physical mechanisms pretending to describe inflation and baryosynthesis. There are also many different candidates for the role of dark matter particles.

Unfortunately, the early Universe, when there were inflation and baryosynthesis as well as dark matter was created, cannot be observed directly by astronomical means. It is therefore necessary to develop a system of indirect methods of correct choices of variants associated with different cosmological scenarios and models of elementary particles on which they are based. The set of elementary particles and quanta of their interaction represent the Lego of the Universe – for different sets we come to different pictures of the Unvierse, its evolution and structure.

Thus the internal development of elementary particle physics requires cosmological verification of the principles of particle physics. On the other hand, this approach which lies in the area inaccessible by direct modern experimental methods, was used to construct the physical principles of modern cosmology.

Clear understanding of the relationship between the fundamentals of macro- and microworlds and the virtual absence of direct experimental and astronomical methods of their research led to the creation of

cosmoparticle physics which studies these foundations on the basis of comprehensive analysis of the effects of their indirect manifestations. The need for such a combination of indirect methods is derived from the main issue of both cosmology and particle physics – the Ouroboros problem: Physical basis of modern cosmology is based on predictions of the theory of elementary particles, which, in turn, look to cosmology for their test. Therefore, being at the forefront of fundamental physics at the largest and smallest scales, nor cosmology or particle physics can examine their grounds alone, no matter how sensitive were the methods of their direct research. These grounds are in such a close relationship that they are practically inseparable. Thus, the frontiers of our knowledge of macro- and microworld converge, and a mystical 'Ouroboros' snake that eats its own tail symbolizes the cycle of problems which fundamental physics faces in its one-dimensional development.

Cosmoparticle physics, offering a non-trivial way out of this vicious circle, is based on the fundamental relationship of the basis of cosmology and particle physics, and opens the possibility in principle to explore these reasons in a complex combination of indirect cosmological, astrophysical and microphysical effects.

The paradoxical form characteristic of the methods of cosmoparticle physics in relation to research in traditional fields of science, is illustrates by the ‘pyramid in the circle’ showing the

multidimensional nature of the solution of the Ouroboros problem.

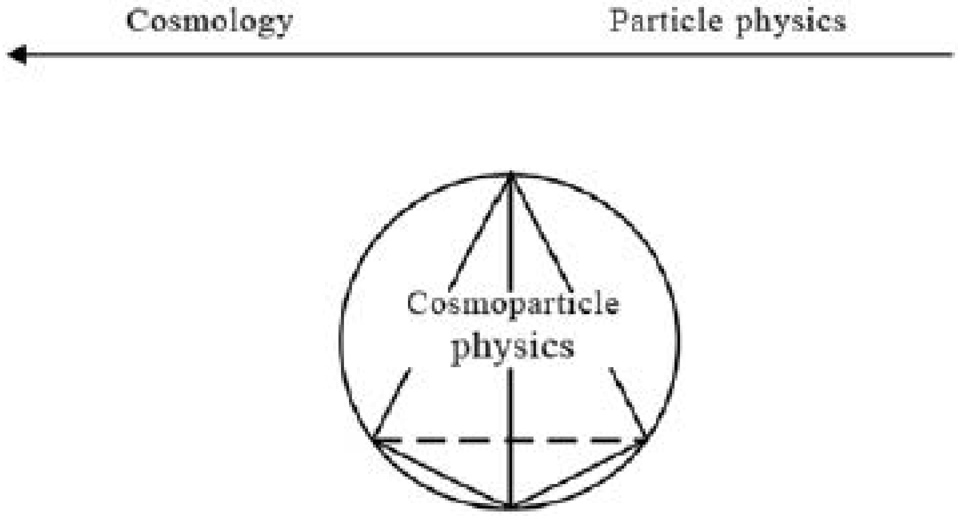

Figure 1: 'Pyramid in the circle'- a multi-dimensional solution of the Ouroboros problem.

Cosmoparticle physics reproduces on the largest and smallest scales the fundamental relationship between the microscopic and macroscopic descriptions, typical for theoretical physics. It offers a new level of this relationship, which, for example, takes place between thermodynamics and atomic physics, hydrodynamics and kinetics. However, the absence of direct experiments on the cosmological scales and in superhigh energy physics on which modern cosmology is based, leads to the need to develop a system of non-trivial indirect methods in cosmoparticle physics. Such methods can be called Cosmoarcheology – search in the astrophysical data for traces of new physical phenomena in the Universe, Cosmoarcheology treats the Universe as a unique natural accelerator in which astrophysical data play the role of a particular experimental result of the thought experiment (Gedanken Experiment), carried out by cosmoarcheology. Cosmological predictions of particle theory maintain cosmophenomenology of new physics – section of cosmoarcheology, studying cosmologically significant effects of new physics in the early Universe and their possible manifestations, which can be verified in comparison with astrophysical data. These predictions include such fantastic possibilities as the existence of antimatter stars in our Galaxy, of invisible mirror world, co-existing with the visible with its own invisible stars and planets, cosmic strings and many other exotic objects…

All that makes the fundamental research in cosmoparticle physics an exciting challenge for the science of this Millennium.