CosmoParticle Physics: Basic Principles and Prospects for Future Development

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Abstract

COSMOPARTICLE PHYSICS is the specific crossdisciplinary field of science, studying foundations of particle physics and cosmology in the combination of indirect cosmological, astrophysical and physical signatures of their fundamental relationship. The possibilities to elaborate unique theoretical grounds for cosmology and particle physics and to study quantitative relationships between cosmological and laboratory effects follow from the basic principles of cosmoparticle physics and open new interesting fields of scientific research in its future development.

1 Principles of cosmoparticle physics

CosmoParticle Physics studies mutual relationship and fundamental physical grounds of Cosmology and Particle Physics \textsuperscript{[1]}. It provides unified treatment of the basic laws of the Universe and elementary particles, establishes mutual correspondence between them and probes the fundamental nature of micro- and macro-worlds in the proper combination of its indirect physical, astrophysical and cosmological effects. It offers the nontrivial way out of the wrong circle of problems, to which fundamental physics comes in its one-dimensional development.

Cosmoparticle physics is now being formed into selfconsistent new science, following internal basic principles in its future development. This development revives the tradition of Natural philosophy of the universal knowledge, the tradition to consider the world in its universal completeness and unity.

Cosmoparticle physics reproduces in the largest and smallest scales the general feature of the fundamental physics: the mutual correspondence between microscopic and macroscopic descriptions, say, between thermodynamics, atomic theory, hydrodynamics and kinetics, or between the

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fundamental macroscopic and microscopic quantities, e.g., between the Avogadro number and the mass of proton. However, at the level of fundamental cosmology and particle physics this correspondence acquires the new quality of their unity.

That is why the first basic principle of cosmoparticle physics is the idea of a world system, treating in the unique framework the foundations of macro- and micro-physics. The second principle assumes, that the world system establishes strict quantitatively definite mutual correspondence between fundamental cosmological, astrophysical and micro-physical laws, i.e. postulates the quantitatively definite correspondence between the structures at macro- and micro- levels. Finally, the third principle assumes, that the set of world system parameters does not exceed the number of its macro- and micro-scopic signatures.

One may easily find, that the first principle simply postulates the existence of a world system, whereas the two other principles specify its necessary properties. The crucial point in this approach is multidimensional solution, offered by the cosmoparticle physics to the problems, both cosmology and particle theory face on. It may be shown, that this approach naturally embeds all the widely known existing trends in studying links between cosmology and particle physics, such as astroparticle physics, theories of everything, particle astrophysics, cosmosmoarcheology.

Here we’d like to specify some new types of links, following with necessity from the basic principles of cosmoparticle physics and lying outside these widely discussed trends.

2 Unified models of cosmology and particle physics

Intensive efforts to construct the finite Theory of Everything, undertaken last decade on the base of Superstring models, have not lead, unfortunately, to extensive theoretical framework, putting together the modern cosmology and particle physics into the detailed and quantitatively definite picture. The point is that the space of classical string vacuum has a vary large degeneracy, and there is no objective criteria that distinguishes a particular string vacuum among the numerous possibilities. The mathematical complexity is multiplied by the enormous variety of possible embeddings of the Standard model (SM) of particle interactions into the structure of superstring models. Indeed, the guiding principle of superstring phenomenology is very simple: it is to reproduce the SM within the effective low energy field theory of a string model. Since only general features such as the gauge group, number of families, etc. are considered, it leads to numerous possibilities for embedding the SM in superstring phenomenology. For example [2], within the framework of perturbative heterotic superstring, the total rank of the gauge group (for \( N = 1 \), space-time supersymmetric models) can be as large as 22. After the SM \( SU(3)_C \otimes SU(2)_W \otimes U(1)_Y \) symmetry with the rank 4 is reproduced, the rank of the residual gauge symmetry can be still as large as 18. Taking into account that the number of models grows (roughly) as a factorial of the rank of the residual gauge symmetry, it becomes clear that we need additional arguments to restrict the amount of models. One of them is to use grand unification and to embed the SM symmetry within a simple gauge group \( G \supset SU(3)_C \otimes SU(2)_W \otimes U(1)_Y \). To break the grand unified gauge group \( G \) down to that of the SM an adjoint representation of Higgs fields must be present in effective field theory among the light degrees of freedom. In perturbative heterotic superstring such states in the massless spectrum are compatible with \( N = 1 \) supersymmetry and chiral fermions only if the
grand unified gauge group is realized via a current algebra at level $k > 1$ (see [3]). This condition leads to reduction of the total rank of the gauge group, and, therefore, restricts the number of possible models. However, for example, for a grand unified gauge group $G = SO(10)$ with, $k = 3$, the rank of the residual gauge symmetry can be still as large as 7. Thus even grand unification constraint allows unacceptable amount of SM embedding. In the case of more sophisticated and extensive string models the ambiguity grows, making virtually impossible to use the main advantage of the string theory – to calculate all the fundamental macro- and microphysical quantities from the first principles.

Moreover, however extensive String models are, they do not represent the most general embedding for the particle physics and the physics of space-time. The following motivations illustrate some idea on the possible form of such a general framework.

Events are basic elements of space-time in relativistic theory. The intervals between them maintain the geometry of space-time. So it seems physically meaningful to treat material processes, causing the events, together with the space-time, they take place in. But such mutual dependence formally should correspond to specific structure of the world, in which unified treatment of internal degrees of freedom (reduced to gauge symmetries) and space-time coordinates may not be completely covered by the string theory. Some more general mathematical framework may be appropriate, e.g. the invariant formulation of the apparatus of fiber bundle theory (see [4] and Refs. wherein), treating space-time and internal variables on equal footing and making it possible to fix the true symmetry of fundamental interactions and geometry of space-time from exact solutions for the functional integral. The realization of such program can lead to the true physically selfconsistent theory of space-time, elementary particles and fundamental natural forces. As a step in this direction, elaboration of unified models of cosmology and particle physics is important. Such models treat physically selfconsistent complete cosmological scenarios. Physical selfconsistency means, that the physical grounds for inflation, baryosynthesis and dark matter are considered in the unified theoretical framework on the base of the unique particle model, and the degree of completeness assumes the accuracy, with which the astronomical observational data are reproduced in the considered cosmological scenario. The degree of completeness of the cosmological model should depend on the properties of the physical model only.

The easiest way to construct cosmologically selfconsistent particle models is to extend the SM by addition to its $SU(3)_C \otimes SU(2)_W \otimes U(1)_Y$ symmetry some other global or local gauge symmetries or by inclusion of the SM symmetry group into more general gauge group. As a result, the extended gauge model contains new particles and fields, related to new symmetries added to the standard model. In the most cases, the masses of new particles and strength of new interactions, mediated by new fields, correspond to superhigh energy scales, inaccessible to direct experimental test at accelerators. At best, experimental high-energy physics can put lower limits on some parameters, related to these scales. The only possibility is to elaborate a system of indirect physical, astrophysical and cosmological constraints on the free parameters of the ”hidden” sector of particle model, to fix them and to specify the cosmological scenario, following from this choice.

The strategy of cosmo particle physics approach to unified models of cosmology and particles can be stipulated as follows:

1. Physically motivated choice for extended gauge particle model.
2. Test for its cosmological selfconsistency – study of its possibility to reproduce cosmological and astrophysical phenomena and effects

3. Determination of free parameters of the "hidden" sector of particle model or set of constraints on them from the combination of indirect cosmological, astrophysical and experimental physical restrictions.

4. Elaboration of complete quantitatively definite cosmological scenario.

5. Formulation of the system of indirect experimental physical and astronomical effects, providing the detailed test of the physical model and cosmological scenario, based on it.

6. Estimation of completeness of this scenario.

Cosmoparticle physics puts traditional methods of observational astronomy and experimental physics into nontrivial multidimensional complex system of links, thus enriching substantially the collaboration between physics and astronomy established by astroparticle physics.

3 The system of links between astronomical observations and laboratory physics experiments

Links between particle physics and cosmology are generally viewed by astroparticle physics as system of linear relations. So, statements [4], that electron neutrino mass is about 30eV, immediately lead to cosmological consequences, since Big Bang cosmology predicts primordial neutrino background with the concentration, equal to 3/11 of the one of relic photons. By multiplying the neutrino mass on the concentration of cosmological neutrino background one immediately found, that the massive neutrino density should dominate in the modern Universe and that gravitational instability in the nonrelativistic gas of massive neutrinos should play the dominant role in the formation of the large scale structure of the Universe. Primordial massive neutrinos were identified with the hot dark matter in the halo being one of the three classes of elementary particle dark matter (DM) candidates.

In general hot DM refers to low mass neutral particles that where still in thermal equilibrium after the QCD phase transition. Hot DM particles have a cosmological number density roughly comparable to that of microwave background photons, which implies an upper limit to their mass of a few ten eV. Neutrinos are the standard example of hot DM, although other possibilities such as Majorons are discussed in the literature. Majorons are the pseudo-Goldstone bosons connected with the Majorana nature of the mass of neutrino. Majorana mass of neutrino corresponds to lepton number violation. In this case lepton number violating processes such as nuclear neutrino-less double beta decay can take place. If at least two types of neutrino are massive and neutrino states of definite mass do not coincide with the states with definite lepton number, neutrino oscillations should take place. In the matter resonant enhancement of neutrino oscillations can take place, what may be the solution for Solar neutrino puzzle at very small values of the difference of neutrino mass squares $\delta m^2 \approx 10^{-6} eV$. The detailed analysis of all these crossdisciplinary links, undertaken by astroparticle physics, could not however lead to any definite conclusion in view of
evident troubles of the simple model of massive electron neutrinos in its confrontation with the observational and experimental data.

The successive experimental measurements of electron neutrino mass in studies of beta spectrum of tritium lead to ambiguous results, not confirming the original claims on the value of \( \sim 30 \text{eV} \). The upper limit on the electron neutrino mass is roughly \( 10 \text{eV} \div 15 \text{eV} \), a more precise limit cannot be given since unexplained effects have resulted in the negative value of \( m(\nu_e)^2 \) in recent tritium beta decay experiments. The (90\% C.L.) upper limit on an effective Majorana neutrino mass 0.65eV from Heidelberg-Moscow \(^{76}\text{Ge}\) neutrinoless 2\(\beta\) decay experiments \([\text{3}]\). The upper limits from accelerator experiments on the masses of the other neutrinos are \( m(\nu_\mu) < 0.17 \text{MeV} \) and \( m(\nu_\tau) < 24 \text{MeV} \) (95\% C.L.). The events that appear to represent \( \bar{\nu}_\mu \rightarrow \bar{\nu}_e \) oscillations followed by \( \bar{\nu}_e + p \rightarrow n + e^+ \), \( n + p \rightarrow D + \gamma \), with coincident detection of \( e^+ \) and the 2.2MeV neutron-capture \( \gamma \) ray in the Liquid Scintillator Neutrino Detector (LSND) experiment at Los Alamos suggest that \( \Delta m^2_{\mu e} = | m(\nu_\mu)^2 - m(\nu_e)^2 | > 0 \) \([\text{4}]\). Comparison with exclusion plots from other experiments implies a lower limit \( \Delta m^2_{\mu e} = | m(\nu_\mu)^2 - m(\nu_e)^2 | > 0.2 \text{eV}^2 \), implying in turn a lower limit \( m_\nu \geq 0.45 \text{eV} \), or \( \Omega_\nu \geq 0.02(0.5/h)^2 \). More data and analysis are needed from LSND’s \( \nu_\mu \rightarrow \nu_e \) channel before the initial hint \([\text{5}]\) that \( \Delta m^2_{\mu e} \approx 6 \text{eV}^2 \) can be confirmed. Recent Super-Kamiokande data following the Kamiokande data \([\text{6}]\) show that the deficit of \( E > 1.3 \text{GeV} \) atmospheric \( \nu_\mu \) increases with zenith angle. These data suggested that \( \nu_\mu \rightarrow \nu_\tau \) oscillations length is comparable to the height of the atmosphere, implying that \( \Delta m^2_{\mu \tau} \approx 10^{-3} \text{eV}^2 \) – which in turn implies that if either \( \nu_\mu \) or \( \nu_\tau \) have large enough mass (\( \geq 1 \text{eV} \)) to be a hot dark matter particles, then they must be nearly degenerate in mass, i.e., the hot dark matter mass is shared between these two neutrino species. However, the deficit of atmospheric \( \nu_\mu \) even at small zenith angles, corresponding to paths much smaller than oscillation length, causes serious doubts in the interpretation of Super-Kamiokande and Kamiokande data \([\text{7}]\). At \( \Omega_\nu \approx 1 \) neutrino free streaming strongly suppresses adiabatic fluctuations at scales smaller than galaxy superclusters (\( \approx 10^{15} \text{Mo} \)). With the use of the COBE upper limit, hot DM with adiabatic fluctuations would hardly lead to any structure formation at all. The proper choice of a possible solution for this problem - transition to more complicated cases, hot DM plus some sort of seeds, such as cosmic strings (see for example \([\text{8}]\)) or to other class of dark matter candidates, corresponding to cold DM (CDM) scenario - has in fact no fundamental grounds in the framework of astroparticle physics. Moreover the physical grounds for neutrino instability or for CDM particles are not alternative to the ones for neutrino rest mass, and from the physical viewpoint the general case should account for all these possibilities. Cold DM consists of particles for which the scale of free streaming is very small and its existence leads to strong dynamical effects at galaxy scale.

The development of CDM models and their troubles in the framework of astroparticle physics seem to confirm the general wisdom on true complexity of the world system. The two sorts for cold DM that are best motivated remain supersymmetric particles (WIMPs) and axions.

Supesymmetry underlies almost all new ideas in particle physics, including superstrings. There are two key feature of supersymmetry that make it especially relevant to DM, \( R \) – parity and the connection between supersymmetry breaking and the electroweak scale. The \( R \) – parity of any particle is \( R \equiv (-1)^{L+B+S} \), where \( L \), \( B \), and \( S \) are its lepton number, baryon number, and spin. In most version of supersymmetry, \( R \) – parity is exactly conserved. This has the powerful consequence that the lightest \( R \) – odd particle – often called the ”lightest supersymmetric partner”
LSP—must be stable, for there is no lighter $R$–odd particle for it to decay into. The LSP is thus a natural candidate to be the dark matter. In the standard version of supersymmetry, there is an answer to the deep puzzle why there should be such a large difference in mass between the GUT scale $M_{\text{GUT}} \simeq 10^{16}\text{GeV}$ and the electroweak scale $M_W = 80\text{GeV}$. Since both gauge symmetries are supposed to be broken by Higgs bosons which moreover must interact with each other, the natural expectation would be that $M_{\text{GUT}} \simeq M_W$ or that $M_W$ is induced by radiative correction $M_W \sim \alpha M_{\text{GUT}}$. The supersymmetric answer to this “gauge hierarchy” problem is that the masses of the weak boson $W^\pm$ and all other light particles are zero until supersymmetry itself breaks. Thus, there is a close relationship between the masses of the supersymmetric partner particles and the electroweak scale. Since the abundance of the LSP is determined by its annihilation in the early Universe, and the corresponding cross section involves exchanges of weak bosons or supersymmetric particles—all of which have electromagnetic-strength couplings and masses $\simeq M_W$—the cross section will be $\sigma \simeq e^2 s/M_W^4$ (where $s$ is the square of the center of mass energy) i.e., comparable to the that of typical weak interaction processes. This in turn has the remarkable consequence that the modern density of LSPs can be close to the critical density, i.e. $\Omega_{\text{LSP}} \simeq 1$. The LSP is in the most cases a spin $-1/2$ Majorana particle called “neutralino”, which represents the linear combination of photino (supersymmetric partner of the photon), zino (partner of the $Z^0$), Higgsinos (partners of the two Higgs bosons associated with electroweak symmetry breaking in supersymmetric theory), and axinos (partner of the axion). Neutralinos are Weakly Interacting Massive Particles (WIMPs) with the mass from tens to hundreds GeV, and thus are natural candidates for the cold DM.

The prediction of invisible axion follows from another line of theoretical argumentation, related to the solution of the strong CP violation problem in QCD. Searches for axion emission in $\mu$, $K$ decays and nuclear decays put lower limit on the scale of axion physics. Constraints on stellar energy losses due to axion emission put this limit even higher: up to $10^6\text{GeV}$ in the case of archion and up to $10^8\text{GeV}$ for the bulk of other invisible axion models. In cosmology, primordial coherent axion field oscillations were found to behave in respect to gravitational instability as gas of very heavy particles, making invisible axion popular CDM candidate. Experimental searches for cosmic and Solar axion fluxes are under way, based on the predicted effect of axion-photon conversion in time–varying electromagnetic field.

In the framework of astroparticle physics it is not possible to find physical motivations which candidate on CDM particle—neutralino or axion—is more preferable. From particle physics viewpoint the both candidates are important, since both supersymmetry and invisible axion solution are necessary to remove internal inconsistencies of the standard model: supersymmetry removes quadratic divergence of Higgs boson mass in the electroweak theory and axion recovers from strong CP violation in QCD. Astroparticle physics has no theoretical tools to find the proper combination for the both hypothetical phenomena. Moreover, recent analysis of the observational data on the large scale structure and of the anisotropy of thermal electromagnetic background find troubles in simple CDM model and favors more sophisticated dark matter scenario, such as mixed cold+hot dark matter (see for example [12]). It appeals for necessity in special methods to deal with multiparameter space of physical and cosmological parameters, which astroparticle physics does not possess.

Together with the proper combination of studies of cosmological large scale structure, relic
radiation, nucleosynthesis, tests for inflational, baryosynthesis and dark matter models cosmoparticle physics invokes such forms of crossdisciplinary studies as cosmoarcheology or experimental physical cosmology.

4 Cosmoparticle approach to the problem of fermion masses and mixing

The problem of fermion families is one of key problems in the modern particle physics. It has different aspects, questioning the origin of family replication, quark and lepton mass spectrum and mixing pattern, CP violation in weak interactions, CP conservation in strong interactions, suppression of flavor changing neutral currents (FCNC), pattern of neutrino masses and oscillations, etc. Thus the particle model of fermion families should offer the solution to all these problems. The standard model (SM) is successful in describing various experimental data (see for example [13]) and it can be considered as a minimal necessary element of any theory of flavor. In SM the three families, sharing the same quantum numbers under the $SU(3)C \otimes SU(2)_W \otimes U(1)_Y$ gauge symmetry, are introduced as an anomaly free set of chiral left-handed fermions $q_i = (u_i, d_i), u^c_i, d^c_i; l_i(v_i, e_i), e^c_i$, where $i = 1, 2, 3$ is a family index. In SM the masses of fermions and $W^\pm, Z$ gauge bosons have the common origin in the Higgs mechanism. Quarks and charged leptons get masses through the Yukawa couplings to the Higgs doublet $\phi$:

$$L_{Yuk} = \lambda_{ij}^u q_i C u_j^c \tilde{\phi} + \lambda_{ij}^d q_i C d_j^c \phi + \lambda_{ij}^e l_i^c C e_j^c \phi$$

So, the fermion masses are related to the weak scale $\langle \phi \rangle = v = 174 GeV$. However, the Yukawa constants are arbitrary, namely $\lambda_{u,d,e}$ are in general complex $3 \times 3$ matrices. To reproduce the masses of quarks and leptons one has to put by hands 27 values of these matrix elements. The SM contains no renormalizable couplings that could generate the neutrino masses:

$$L_{\nu} = \frac{\lambda_{ij}^\nu}{M} (l_i \tilde{\phi}) C (l_j \tilde{\phi})$$

where $M >> v$ is the regulator mass, which depends on the mechanism of neutrino mass (2) generation. The matrices of coupling constants and the corresponding fermion mass matrices $\hat{m}^f = \hat{\lambda}^f v$ ($f = u, d, e$) and $\hat{m}^\nu = \hat{\lambda}^\nu (v^2 / M)$ can be reduced to the diagonal form by the unitary transformations $V_f$ and $V_\nu$. Hence, quarks are mixed in the charged current interactions, and these mixings are determined by Cabibbo- Kobayashi-Maskawa (CKM) matrix. The CKM matrix is parameterized by three mixing angles and CP-violating phase. In the case of massive neutrinos, a similar mixing matrix emerges also in the lepton sector. The fermion family puzzle consists in the following phenomena: the mass spectrum of quarks and charged leptons is spread over five orders of magnitude, from MeVs to hundred GeVs; the weak transitions dominantly occur inside the families, and are suppressed between different families thereby the SM exhibits the natural suppression of the flavor changing neutral currents (FCNC), both in the gauge boson and Higgs exchanges; the Yukawa constants in 1 are generally complex, the observed CP-violating phenomena can be explained by the CKM mechanism with sufficiently large CP-phase $\simeq 1$. However,
at the same time it induces the strong CP violation problem (see for example \[14\]): the overall phase of the Yukawa matrices gives effective contribution to the vacuum $\Theta$- term in QCD and thus induces the P and CP violation in strong interactions. On the other hand, the measurements of dipole electric moment of neutron impose the strong bound $\Theta < 10^{-9}$; the experimental data show some ambiguous indications for neutrino masses and mixing. The fermion mass and mixing problem can be formulated as a problem of matrices of the Yukawa couplings $\hat{\lambda}^f$, which remain arbitrary in the SM. There is no explanation, what is the origin of the observed hierarchy between their eigenvalues, why $\hat{\lambda}^u$ and $\hat{\lambda}^d$ are small, what is the origin of the complex structure needed for the CP- violation in weak interactions, why the $\Theta$- term is vanishingly small in spite of the complex Yukawa matrices. It is attractive to think that at some scale above the electroweak scale there exists a more fundamental theory which could allow to calculate the Yukawa couplings, or at least to fix the relationship between them.

The structure of mass matrix can be related with the spontaneously broken horizontal symmetry between fermion families. Consider, for example, model with all quark and lepton states transforming as triplets $f^\alpha = (q, l, d^c, e^c)^\alpha$ of the horizontal $SU(3)_H$ symmetry \[15\], ($\alpha = 1, 2, 3$ is a family index). Such a horizontal symmetry does not allow quarks and leptons to have renormalizable Yukawa couplings. Thus, the fermion mass generation is possible only after the $SU(3)_H$ breaking, through the high order (non-renormalizable) operators (HOPs) involving some "horizontal" Higgses inducing this breaking at the scale $V_H \gg v$. This suggests that the observed mass hierarchy may emerge due to the hierarchy in the $SU(3)_H$ breaking. Full $SU(3)_H$ breaking is achieved by introducing the horizontal scalars: a sextet $\chi^{[\alpha\beta]}_3$ and two other sextets or triplets $\chi^{[\alpha\beta]}_{1,2} \simeq \varepsilon^{\alpha\beta\gamma}\chi_\gamma$. The pattern of their $3 \times 3$ VEV matrix can be chosen so that the first sextet VEV is acquired by $(3, 3)$ component, and in sextets (or triplets) $\chi_2$ and $\chi_1$ the smaller VEVs $V_{23}$ and $V_{12}$ are acquired by $(2, 3)$ and $(1, 2)$ (or first and third) components. VEVs follow the hierarchy $V_{33} \gg V_{23} \gg V_{12}$, which is stable relative to radiative corrections. Thus in the context of the $SU(5) \otimes SU(3)_H$ theory with fermions in representations $(5 + 10)_{\alpha}$, the relevant HOPs \[15\] can be induced through the renormalizable interactions, as a result of integrating out the effects of hypothetical superheavy particles (see, for example, \[16, 17\]). In the other words, the quark and lepton masses can be induced through their mixing with superheavy fermions, in a direct analogy to the see–saw mechanism of neutrino mass generation. In this case the VEV pattern of Higgs multiplets $\chi$ is reflected in the Yukawa matrices, and the fermion mass hierarchy follows the hierarchy of $SU(3)_H$ symmetry breaking. There are two possible choices for the representation of $F$–fermions, and, respectively, one can generate two types of the pattern of Yukawa mass matrices \[18, 19\]. The first case corresponds to a direct hierarchy pattern. In particular, the VEV pattern leads directly to the Fritzch texture. Another possibility is the inverse hierarchy. In the latter case the VEV pattern is inverted in the fermion mass structure (see more detail \[18, 19, 17\]). Thus, the horizontal $SU(3)_H$ symmetry is attractive since it unifies all families. For the solution of the strong CP- problem one can introduce the Peccei-Quinn (PQ) type symmetries \[20\], which in additionally could further restrict the mass matrix structure. In particular, in the horizontal $SU(3)_H$ symmetry models the PQ symmetry can be naturally related to the phase transformation of the horizontal scalars $\chi$ \[18, 19\]. Consider as an example the application of the approach of cosmoparticle physics (section 2) to the problem of fermion flavours. This strategy can be stipulated as follows.
**Step 1.** The class of physically motivated extensions of SM is considered, namely, the class of
gauge models with horizontal family symmetry.

**Step 2.** The inevitable consequences of chosen class of models, which are able to reproduce
cosmological and astrophysical phenomena and effects are the following:

- the existence of the specific type of invisible axion (archion), which is simultaneously Majoron
  and familon \[18, 19\];
- the existence of horizontal scalars $\chi$ with superhigh energy scale of VEVs;
- the existence of neutrino Majorana mass with the hierarchy of neutrino masses;
- the nonconservation of lepton number $\Delta L = 2$;
- the instability of neutrino relative to decays on more light neutrino and archion;
- the Dirac see-saw mechanism and singlet scalar $\eta$, connected with it;

**Step 3.** One introduces the main free parameter $V_H$ of the hidden sector of the considered
model, namely, the scale of horizontal $SU(3)_H$ symmetry breaking. The set of indirect cosmolog-
al, astrophysical and experimental physical restrictions on the hidden sector is revealed from
following phenomena:

- from the analysis of data of nondiagonal transitions (for example $\mu \to ea$ and $K \to \pi a$
  (where $a$ is archion)) \[21, 22\];
- from the astrophysical estimations of stellar energy losses due to archion emission \[19\];
- from the analysis of archion emission influence the time scale and energetics of neutrino flux
  from collapsing star \[19\];
- from the analysis of inhomogeneities generated by the large scale modulation of coherent
  axion field oscillations \[23, 24, 25\];
- from the analysis of primordial black holes formation in the second order phase transitions
  connected with three stages of horizontal $SU(3)_H$ – symmetry breaking, which take place
  at the inflationary stage \[26, 25\];
- from the effect of nonthermal horizontal symmetry restoration at postinflational dust-like
  stage \[23, 27\];

Taking together all limits imposed by the pointed phenomena it is possible to extract two narrow
windows for the value of the parameter $V_H$. They are the ”low” energy branch $V_6$ \[24, 28\] and the
”high” energy branch $V_{10}$ \[25\].

**Step 4.** With the use of the above restrictions one can elaborate the physically motivated
full cosmological model, which is based on the chosen horizontal extension of SM. This model has
been called the model of ”horizontal” unification (MHU) \[24, 25\].
• MHU solves the problems of SM connected with family problem and strong CP violation problem in QCD; it predicts qualitatively new type of invisible axion (archion) \[18, 19, 29\]; it predicts the neutrino masses and neutrino flavour nondiagonal transitions with emission of archion.

• MHU predicts the following history of Universe:
  
  – The early Universe starts from the inflational stage \[24, 25\], driven by the inflaton field \(\eta\), being singlet relative to all gauge groups. The VEV of this field plays the role of the universal energy scale in the Dirac see-saw mechanism of the generation of masses of charged fermions \[17, 18, 24, 25\]. When the inflational stage is finished the inflaton field decays due to interactions assumed by the Dirac see-saw mechanism \[24, 25\]. It leads to reheating of the Universe and consequently to transition to the standard Friedman cosmology.
  
  – The reheating temperature is sufficiently high for generation of the observed baryon asymmetry. The baryogenesis mechanism in the MHU combines the \((B+L)\) nonperturbative electroweak nonconservation at high temperatures with \(\Delta L = 2\) nonequilibrium transitions, induced by Majorana neutrino interaction \[24\]. The mechanism can provide inhomogeneous baryosynthesis and even to the existence of antimatter domains in baryon asymmetrical Universe \[24\].
  
  – There are two possible scenarios of large scale structure (LSS) formation:
    
    * Hierarchic decay scenario (HDS) \[24, 22\], realized at the ”low” energetic scale \(V_6\). In the HDS the LSS formation takes place in the succession of stages of dominance of unstable neutrino and their relativistic decay products.
    
    * Mixed stable dark matter, realized at ”high” energetic scale \(V_{10}\) \[25\]. The formation of LSS in this case occurs at the conditions of dominance of coherent oscillations of axion field and massive stable neutrino (see \[24\] in more detail).

**Step 5.** The system of the detailed indirect test of MHU and MHU-based cosmological scenario can use the following signatures:

• MHU predicts flavour nondiagonal decays of leptons, mesons and hyperons (see \[22, 28\] in more detail);

• MHU predicts the level of oscillations \(K \rightarrow \bar{K}, B \rightarrow \bar{B}\) \[24\];

• astronomical search for invisible axions (see for example \[30\]) and their two-photon decays;

• experimental searches for solar axions (see for example \[31\]);

• experimental searches for the force, violating the Equivalence Principle, which is connected with the existence of invisible axion (see for example \[32\]).

**Step 6.** The estimation of completeness of obtained scenario is necessary to determine the direction of the further extension of the considered approach. In the other words the elaborated
cosmological model should incorporate the cosmological consequence of some other extensions of the SM such as GUT and SUSY. In particular, the estimation of completeness of MHU can be obtained by the comparison of the predicted consequences of the MHU-based scenario of inflation, baryosynthesis and LSS formation with the astronomical observations (see [25] in more details).

To conclude, the development of cosmology and particle physics and the nontrivial tests of their foundations in combination of indirect evidences follow the laws of cosmparticle physics, that will unify on the basis of its principles the existing trends in studies of mutual relationship of elementary particles and the Universe, widely represented in the present proceedings.

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