COSMOARCHEOLOGY: ASTROPHYSICAL PROBES FOR NEW PHYSICS IN THE EARLY UNIVERSE

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ABSTRACT. The original Gamov's Big Bang cosmology has evolved for the last decades to the modern cosmology, losing the direct relationship with the experimentally proven physical laws. It is the aim of cosmoparticle physics to study both the early Universe and the physics, governing its evolution, in the combination of their indirect cosmological, astrophysical and physical effects. Cosmoarcheology is the important branch of this research. It undertakes the Gedanken Experiment, tracing cosmological signatures for the new physics in the astrophysical data. The main ideas of the modern cosmology find their physical origin in the hypothetical processes in the early Universe: the total density is related to the result of inflation, the baryon density - to baryosynthesis and the dark matter - to primordial particles and/or fields generated before the 1 s of cosmological expansion. The physical mechanisms for these processes are based on predictions of particle theory. To specify the physical origin of the cosmological functions one needs the additional model-dependent cosmological effects, that can be referred to as the hidden functions of the modern cosmology. Cosmoarcheological analysis finds the spectrum of primordial black holes, inhomogeneous baryosynthesis and multicomponent dark matter as important signatures of the new physics in the early Universe, related to a wide class of physical realisations of cosmological models. Such analysis predicts new phenomena in the Universe, which can be the subject of astronomical discoveries in the next decades, such as mirror matter, 4th type of neutrino, or macroscopic antimatter in baryon asymmetrical Universe. In particular, it follows from this analysis, that the halo of our Galaxy can contain up to 100000 antimatter stars. Cosmoarcheological chains link the processes in the early Universe to the effects after the first second, which can be tested in the observations of the thermal background, of the baryon matter space distribution and chemical composition, of non-thermal electromagnetic backgrounds and cosmic rays. The important role of cosmoarcheological methods is illustrated on the example of the model of horizontal unification. The model proves that in no case the physically self-consistent realisation of inflation, baryosynthesis and dark matter can be reduced to these three phenomena only. Cosmoarcheological analysis of the additional cosmological consequences, following from such realisations, provides the principal possibility to reproduce the physics of early Universe in all its nontrivial complexity.

Key words: cosmology: inflation, baryosynthesis, dark matter, antimatter, black holes: primordial black holes; elementary particles: quarks, leptons: neutrino; cosmoparticle physics.

1. Introduction

The modern cosmology is based on the two observational facts, namely, that the Universe expands and that the Universe contains the electromagnetic black body background radiation. Putting them together one comes to the Gamov's ideas of big bang Universe. One inevitably comes to the conclusion, that at earlier stages of cosmological expansion the physical conditions in the Universe should have been much different from what we observe now. Extrapolating, or more precisely interpolating, the law of cosmological expansion to the past, one finds, that at much earlier stages of cosmological expansion energy density of radiation exceeded the matter density, so that the radiation dominance stage should have taken place. One can easily check that matter and radiation were in equilibrium, that there were no galaxies, stars, but the matter was in the form of nearly homogeneous plasma. Gamov's big bang scenario was a self-consistent combination of general relativity, thermodynamics and well prove n in laboratories laws of atomic and nuclear physics, successively applied to the evolution of the Universe as a whole, under the assumption that only baryon matter and electromagnetic radiation (and neutrinos) maintain its content (see review in Zeldovich, Novikov,1975). According to this scenario at the first three minutes nuclear reactions should have taken place, leading to the primordial chemical composition. This picture found qualitative confirmation in the comparison of predictions of big bang nucleosynthesis with the observed light element abundance. It gave qualitative explanation to the observed structure of inhomogeneities as a result of gravitational instability in nearly homogeneous matter. However, quantitative disagreements turning to be more and more profound made the whole picture controversial, unless some additional fundamental elements are added to the basis of the whole construction. These additional elements found physical motivation in the development of parti cle theory.

In the Gamov's cosmology it was reasonable to take into account only electrons, nucleons, photons and neutrino from hundreds elementary particles, discovered at accelerators, since only stable particles are of cosmological importance. In particle theory stability reflects the conservation law, which from Noether's theorem follows from fundamental particle symmetry. Electron is stable owing to electric charge conservation and proton's stability reflects conservation of baryon charge. Though the standard model of weak, electromagnetic and strong interactions, built on the basis of the generalisation of gauge principle of Quantum Electrodynamics, finds no experimental contradictions, there are internal inconsistencies and esthetical reasons, which lead the particle theory beyond the standard model. New symmetries and mechanisms of their breaking result in new conservation laws and macroscopic phenomena, having important cosmological consequences - phase transitions in the early Universe, stable and metastable particles, topological defects etc.

The account for these consequences of particle theory made it possible to approach the principal questions: why the Universe expands? why its initial conditions were so close to flat Universe? why they were so similar in causally disconnected regions? why it contains matter and no antimatter? Does baryon matter dominate in the modern Universe?, which had no fundamental answers in the old cosmological picture. The modern cosmology retains the main spirit of Gamov's approach - to treat the Universe as the physical process, but physical laws governing this process also turn to be the subject of study. The exciting challenge to elaborate both the true theory of the Universe and the true physics, underlying it, is the topic of the present paper.

2. The modern description of big bang Universe – inflationary cosmology with baryosynthesis and dark matter

The first three questions found principal solution in inflationary cosmological models (Guth, 1981), assuming the existence of a stage of superluminous (in the simplest case exponential) expansion in the very early Universe. Such a stage can not be provided by matter, radiation or relativistic plasma dominance, but can be realised under some conditions as cosmological consequence of particle theory, c.f. in strong first order phase transition or by slow rolling down of scalar field to its true vacuum state. Simultaneously inflationary models found the physical mechanisms for generation of the spectrum of initial fluctuations. Most of these effects are related to experimentally inaccessible parts of particle theory, in particular, to the mechanisms of symmetry breaking at supehigh energy scales. One can also find, that different inflationary models follow from different theoretical grounds and in general may coexist in the complete cosmological scenario.

A.Sakharov (1967) and then V.Kuzmin (1970) were first, who related the observed baryon asymmetry of the Universe to the generation of baryon excess due to out-of-equilibrium CP violating effects in hypothetical baryon nonconserving processes at very early stages of the initially baryon symmetric Universe. Grand unified models have provided physical basis for these original ideas of baryogenesis, having the existence of baryon non conserving interactions among their predictions. The mechanisms of baryosynthesis found then some other grounds in supersymmetric models, where primordial condensate of scalar quarks is possible, resulting in baryon excess after scalar quarks decay on ordinary quarks, and even in the standard model, leading to baryon nonconservation at very high temperatures, provided that it is extended by larger Higgs sector and/or by inclusion of lepton number violating processes, related to neutrino Majorana mass generation mechanism.

The discrepancy between the estimated baryon density and the total density of the Universe is ascribed in the modern cosmology to the existence of non-baryonic dark matter. Namely, the level of initial fluctuations, needed in the old big bang scenario to provide the formation of the observed large scale structure of the Universe, turned to correspond to the expected effect in anisotropy of thermal electromagnetic background inconsistent with the observed level of its isotropy. On the other hand, low baryonic density, one needs to reproduce the observed light element abundance as a result of big bang nucleosynthesis (see review in Schramm,Copi,1996), was inconsistent with much higher density, one needs to provide the formation of the large scale structure as a result of development of gravitational instability on matter dominated stage. In the simplest cases dark matter is associated with primordial weakly interacting particles, originated from early Universe - massive neutrino (hot dar k matter, HDM), invisible axions or neutralino (cold dark matter, CDM) or unstable neutrino (UDM). However different are from the cosmological viewpoint the models of large scale structure formation by hot, cold, unstable dark matter, or more sophisticated models, implying cosmic strings plus hot dark matter, late phase transitions etc, they are not alternatives from the viewpoint of particle physics, having grounds in different and in general complementary parts of hidden sector of particle theory. So, in principle, the mixture of all of them should be considered as the general case.

So the modern cosmological picture reflects the principle change in our understanding, what big bang cosmology is. From self-consistent but basically controversial and incomplete old big bang scenario we come to the picture of inflationary cosmology with baryosynthesis and (multicomponent?) nonbaryonic dark matter. Thus, directly or indirectly, Gamov's big bang theory is supplemented in the modern standard big bang Universe by at least three necessary elements (inflation, baryosynthesis and nonbaryonic dark matter), based on the physical laws, predicted by particle theory but having no experimental proofs. There is a wide variety of different physical mechanisms for inflation, baryosynthesis, various candidates on the role of dark matter particles and, since both the early Universe, when inflation and baryosynthesis should have taken place, and dark matter could not be observed directly by astronomical means, one should elaborate the system of indirect means to make the proper choice between these variants, corresponding to various cosmological scenarios and particle models, underlying them.

The problem is that the space of cosmological and physical parameters is, in general, multidimensional, since physical grounds for different mechanisms of inflation, baryosynthesis and different candidates for dark matter follow from different physical motivations and are not in general alternative but complementary. On the other hand, cosmological tests for particle models should, in general, account both for the particular realization of inflation, baryosynthesis and dark matter and for the additional modifications of cosmological scenarios, corresponding to the chosen realization. Cosmoarcheology, searching in the astrophysical data for the footprints of new physical phenomena in the Universe, may be viewed as already existing branch of proper CosmoParticle Physics (Khlopov,1999), in which all its components are mixed up in a nontrivial manner, resulting in a set of astrophysical probes for the existence and possible properties of hypothetical particles, fields, objects and phenomena predicted as cosmological consequences of particle theory.

Cosmoarchelogy treats the Universe as a unique natural accelerator laboratory, so that the astrophysical data play here the role of specific experimental sample in Gedanken Experiments, Cosmoarcheology undertakes. As in any experiment, to achieve meaningful result one should have precise understanding of the experimental device used, as well as to develop the methods of data sampling and analysis. The problem is, that in the Universal particle laboratory both the source and detectors are out of control. Astrophysical processes can not be directly reproduced in laboratories, but however complicated the combination of effects is, theoretical astrophysics uses, as a rule, in its analysis natural laws, proven in experiment. The trouble is, that in theoretical treatment of the Universe and its evolution the basic physical laws are not known. It makes selfconsitent formulation of cosmoarcheological approach to be, in general, model dependent. One should account for the relationship between the hypothetical particle or field, probed by the astrophysical data, and the physics, underlying inflation, baryosynthesis and nonbaryonic dark matter. And, since the latter is model dependent, one should consider cosmological consequences of the considered hypothesis refered to the picture of cosmological evolution, based on the chosen particle model, underlying these necessary elements of the modern cosmology. It means, that the cosmological trace of hypothetical particle or field may be multi-step, following the nontrivial cosmological path, the model implies.

On the other hand, one should expect, the real picture of cosmological evolution to be much more complicated, than the original Gamow's big bang scenario, and generally more sophisticated, than simple addition of inflation, baryosynthesis and nonbaryonic dark matter dominancy to the scenario of Gamov's Universe. The reason is, that any physically reasonable theoretical framework, giving rise to the necessary elements of cosmology, is generally much more extensive, supplementing these elements by a number of additional cosmologically viable details. Testing these details, cosmoarcheology extends the might of observational cosmology in its probe for the true theory of the Universe.

3. Cosmological probes for physical nature of inflation, baryosynthesis and dark matter

Assuming, that inflational baryon asymmetrical cosmology with nonbaryonic dark matter is more close to reality, than Gamow's original big bang scenario, one should face on the problem of observational evidences, specifying the choice for inflational model, mechanism of baryosynthesis and for the proper form of nonbarynic dark matter.

3.1. Tracers for the mechanism of inflation

One considers inflation as necessary element of cosmological picture. Inflational models explain, why the Universe expands. They provide solution for horizon, flatness, magnetic monopole etc problems (Guth,1981, see review in Khlopov,1999). The solution is based on superluminous expansion, taking place for equation of state $p < -frac\epsilon 3$. Neither matter, nor radiation dominance can provide such an equation of state. One needs some hypothetical phenomena to occur in the very early Universe, inducing unstable negative pressure stage of cosmological evolution. Such hypothetical processes may be related to R^2 effects in gravity, to strong first order phase transitions, or to slow rolling down of effective potential to the true vacuum state. To make the proper choice between these possibilities, or, at least, to make some cut in their wide variety, additional traces of inflational mechanism should be considered. - Fluctuations on inflational stage induce the spectrum of initial density fluctuation, giving rise to galaxy and large scale structure formation in respective scales. The amplitude of these fluctuations is constrained by the observed isotropy of the thermal electromagnetic background. It rules out all the inflational models with high amplitude of predicted fluctuations, the most of GUT induced phase transition scenarios, in particular. In simplest models with quasi-De Sitter close to $p = -\epsilon$ equation of state on inflational phase flat Harrison-Zeldovich form of the spectrum is predicted. Then the estimated amplitude of initial fluctuations at the modern LSS scale provides some information on the possible inflaton properties, e.g. on the form and parameters of scalar field potential. - For more complicated inflational models, e.g. multicomponent inflation, the form of the predicted spectrum of fluctuations may differ from simple flat one. Phase transitions on inflational stage lead to specific peaks or plateaus in the spectrum with the position and amplitude defined by the parameters of the model. One should also account for phase transitions after the global inflational stage, in which the initial spectrum may be modified. - Both in R^2 and scalar field driven (c.f. chaotic) inflational scenarios long dust-like post-inflational stage appears, induced by coherent inflaton field oscillations. The duration of such stages defines the maximal temperature of the Universe after reheating, when radiation dominance stage starts. It also defines the specific entropy of the Universe after reheating. - Initial density fluctuations grow on postinflational dust-like stage, following the general law of development of gravitational instability on matter dominated stage in expanding Universe $frac\delta\rho rho = \delta_0 fractt(_0)^{2/3}$. If the ratio of cosmological timescales, corresponding to the end, t_1 , and the beginning, t_0, of the dust-like stage exceeds ${\delta_0}^{-frac32}$ where δ_0 is the amplitude of fluctuation, in the respective scale inhomogeneity is formed. Evolution of such inhomogeneity may lead to primordial black hole (PBH) formation. Spectrum of PBHs reflects the scales, at which inhomogeneities are formed as well as the mechanism of PBH formation. The minimal probability W_{PBH} of PBH formation is ${\delta_0}^{13/2}$, estimated for direct formation of PBHs in contraction of a very small fraction of configurations, evolved from specifically isotropic and homogeneous fluctuations (see Refs. in Khlopov, 1999). The account fo r PBH formation in a result of evolution of the bulk of inhomogeneities strongly increases the amount of expected PBHs. - Peaks in the spectrum of density fluctuations, produced at inflational stage, may also induce PBH formation even on radiation dominance stage with the probability $W_{PBH}\ exp{-frac118{\delta_0}^2}$.

3.2. Antimatter trace for inhomogeneous baryosynthesis

The generally accepted motivation for baryon asymmetric Universe is the observed absence of antimatter at macroscopic scales up to the scales of clusters of galaxies. In baryon asymmetric Universe the observed baryonic matter is originated from initial baryon excess, surviving after local nucleon-antinucleon annihilation, taking place at the first millisecond of cosmological evolution. The baryon excess is assumed to be generated in the process of baryogenesis (Sakharov,1967; Kuzmin,1970 see review in Khlopov,1999), resulting in baryon asymmetry of initially baryon-symmetrical Universe. It turned out, that practically all the existing mechanisms of baryogenesis may under some conditions lead to inhmogeneous baryosynthesis and even to generation of antibaryon excess in some places. So inhomogeneities of baryon excess distribution and even domains of antimatter in baryon asymmetric Universe may provide a probe for the mechanism of baryogenesis.

In the original Sakharov's scenario of baryosynthesis CP violating effects in out-of-equilibrium B-nonconserving processes, say decays of some particles X, generated in charge symmentric Universe with equal amount of X and their antiparticles baryon excess proportional to n_X and $Im\phi$, ϕ being CP violating phase. If sign and magnitude of $\phi(x)$ varies in space, the same out-of-equilibrium B-nonconserving processes, leading to baryon asymmetry, results in $B(x)$ and in $B(x) < 0$ in the regions, where $Im\phi(x) < 0$. Spatial dependence of ϕ is predicted in model of spontaneous CP violation or in models, where CP violating phase is associated with the amplitude of invisible axion field. The size and amount of antimatter in domains, generated in this case, is related to the parameters of models of CP violation and/or invisible axion (see review in Khlopov,1999; Khlopov, Chechetkin,1987; Chechetkin et al,1982, Khlopov,1992).

SUSY GUT motivated mechanisms of baryon asymmetry imply flatness of superpotential relative to existence of squark condensate. Such a condensate, being formed with B¿0, induces baryon asymmetry, after squarks decay on quarks and gluinos. However the mechanism doesn't fix the value and sign of B in the condensate, opening the possibilities for inhomogeneous baryon charge distribution and antibaryon domains (Khlopov,1999; Chechetkin et al,1982, Khlopov,1992).

New approach to baryosynthesis, based on electroweak baryon charge nonconservation at high temperatures, also imply the possibility of antimatter domains, e.g. due to spontaneous CP violation (Comelli et al, 1994).

So antimatter domains may appear in baryon asymmetric Universe and may be related to practically al the mechanisms of baryosynthesis, to mechanisms of CP violation and to possible mechanisms for primordial baryon charge inhomogenity. The size of domains depends on the details of the respective phase transitions and initial distributions of spatial variable CP violating phase, what accounting for inflation may be as large as the modern horizon, being the case for the models of "island Universe" (Dolgov et al,1987) with very large scale inhomogeneity of baryon charge distribution.

General parameters of the averaged effect of the domain structure are the relative amount of antimatter $\Omega_a = frac\rho_a\rho_{crit}$, where ρ_a is the averaged over large scales cosmological density of antimatter and $\rho_{crit} = frac3H^2 8\pi G$ is the critical density, and the mean size of domains, l, (the characteristic scale in their distribution on sizes) or for small domains, t_{an}, the timescale of their annihillation with the surrounding matter.

Dense antimatter domain with the size exceeding the survival scale can form antimatter globular cluster in our Galaxy. It was recently shown (Khlopov,1998; Belotsky et al,1999) that the minimal mass of such cluster is determined by the survival scale and the maximal total mass of antimmatter stars in our Galaxy is constrained by the galactic gamma ray background. Such cluster should be the galactic source of antinuclear component of cosmic rays, which is accessible in all the allowed range to search for antimatter in AMS experiment on Alpha station (Battiston,1999).

3.3. Multicomponent dark matter

The main arguments favouring nonbaryonic nature of dark matter in the Universe are big bang nucleosynthesis (BBN) in inflational cosmology and formation of large scale structure of the Universe at the observed isotropy of relic radiation. The first line of arguments accounts for the reasonable fits of BBN predictions to the observed light element abundance at $\Omega_b < 0,20$ and the predicted by inflational cosmology $\Omega_{tot} = 1$, ascribing the difference to nonbaryonic dark matter. The second type of arguments is that one can not accommodate both the formation of the large scale structure and the observed isotropy of thermal electromagnetic background without some weakly interacting form of matter triggering structure formation with minor effect in relic radiation angular distribution (see review in Khlopov,1999). There are several scenarios of structure formation by hot (HDM), cold (CDM), unstable (UDM), mixed hot+cold (H+CDM), hierachical decaying (HDS) etc dark matter. These scenarios physically differ by the ways and succession in which the elements of structure are formed, as well as by the number of model parameters. But having in mind general independence of the motivations for each type of dark matter candidates, one finds from particle physics viewpoint hot, cold, unstable etc dark matter not as alternatives but as supplementary options to be taken together, accounting for the whole set of reasonable physical arguments.

Indeed, one considers the would be eV-(10eV)- neutrino mass as physical motivation for hot dark matter scenario. But massive neutralinos, predicted in supersymmetric models, or invisible axions, following from Peccei-Quinn solution of strong CP violation problem in QCD, being cold dark matter candidates, are based on physical grounds, which are in no case alternative to the physics of neutrino mass. So mixed hot+cold dark matter scenarios seem to be physically more reasonable, than simple one-parameter HDM or CDM models. However, all these motivations do not correlate with the problem of quark lepton families, of the existence of three types of neutrinos. Physical mechanisms of family symmetry breaking lead to new interactions, causing massive neutrino instability relative to decay on lighter neutrinos and light Goldstone boson, familon or singlet Majoron.

Neutrino instability, intimately related to family symmetry breaking, provides physical grounds for unstable dark matter (UDM) scenarios (Khlopov,1999). At the expense of additional parameter (unstable particles lifetime) UDM models remove the contradiction between the data on the total density within the inhomogeneities, $\Omega_{inhom} < 1$, and the prediction of inflational cosmology, $\Omega_{tot} = 1$ ascribing the difference in Ω to homogeneous background of unstable particles decay products. UDM models also recover the disadvantages of HDM scenarios, related to too rapid evolution of the structure after its formation. Owing to neutrino instability large scale structure, formed at redshifts corresponding to observed distant objects, survives after the major part of dark matter, having formed the structure, decayed.

The actual multicomponent content of dark matter may be extremely richer, if one takes into account the hypothesis on shadow matter, following from the need to recover the equivalence of left- and right- handed coordinate systems in Caluzza-Klein and superstring models. One meets the problem to account for the whole set of matter fields and interactions, arising from E_8' sector of heterotic string $E_8 x E_8'$ model. Mirror and shadow particles represent the nontrivial dissipational form of dark matter. In the contrary to the usual dark matter candidates - weakly interacting particles, being in the form of collisionless nondissipating gas, mirror and shadow matter can form dense star-like dark matter objects. Such objects, causing microlensing effects in our Galaxy, may be responsible for the observed MACHO events.

Even the above list of options, far from complete, poses the serious problem of the proper choice of the true combination of various dark matter candidates in physically motivated multicomponent dark matter scenarios.

Thus, since physical grounds for all the nonbaryonic dark matter candidates are outside the standard model and loose the proper experimentally proven basis, we either have to take into account all the possible ways to extend the standard model, treating all the candidates as independent, or find a quantitatively definite way to estimate their relative contribution.

4. Cosmological probes for particle theory

The physical basis for inflation, baryosynthesis and dark matter candidates is associated with the new physics, following from the particle theory. One has to use all the indirect means to probe this new physics, and cosmological tests play important role in these methods. One needs cosmologically viable consequences of particle models for such tests, which are generally related to stable or sufficiently metastable particles or objects predicted in them. Since (meta)stability is based in particle theory on some (approximate) conservation law, reflecting respective fundamental symmetry and/or the mechanism of symmetry breaking, cosmoarcheology probes the most fundamental new laws of Nature, assumed by respective extension of standard model.

Indeed, new symmetries, extending the symmetry of standard model, imply new charges, conserved exactly or approximately, and the lightest particle posessing respective charge should be either stable or metastable. The new charges may be related to local or global, continuous or discrete symmetry. They may be topological, induced by the topology of respective symmetry group. In the most cases the mass of hypothetical particles and objects reflects the new fundamental physical scale, at which the assumed symmetry is broken. So let's give some examples, referring to the book (Khlopov,1999) for details. - In all the GUT models, unifying electromagnetism with other forces within compact group of symmetry magnetic monopole solutions appear as topological point object, bearing Dirac magnetic charge $g = hc/e$ and having the mass of the order Λ/e, where Λ is the scale, at which U(1) symmetry, corresponding to electromagnetism, separates from the rest of interactions. - Some specific GUT models imply topology of symmetry group, leading to the existence of domain wall (spontaneously broken discrete symmetry), cosmic string (spontaneously broken U(1) symmetry), wall-surrounded-by-strings etc topological solutions. The respective unit surface (unit length) energy density is of the order of the respective power of the scale Λ of symmetry breaking, i.e. Λ^3 for walls and Λ^2 for strings. - R symmetry (exact or approximate) protects in supersymmetric models (meta)stability of the lightest supersymmetric particle (LSSP). Its mass is generally related to the scale of supersymmetry breaking. In local supersymmetric models this scale also defines the mass of gravitino - supersymmetric partner of graviton, having semigravitational coupling to other particles, inversely proportional to the Planck scale m_{Pl}. - See-saw mechanism of neutrino mass generation implies heavy right-handed neutrino with the Majorana mass M_R related to the scale of lepton number nonconservation. The Majorana mass of the ordinary left-handed neutrino is given by $m_\nu = fracm_D^2 M_R$, where m_D is the Dirac mass of fermions (typically related to the mass of respective charged lepton). The lifetime of the heavy right-handed neutrino, determined by its mixing with the left-handed one ($fracm_D M_R$), turns to be inveresely proportional to mass of light left-handed neutrino. - Spontaneous breaking of Peccei-Quinn symmetry, used to remove the problem of strong CP violation in QCD, results in the existence of (pseudo)Goldstone boson, axion, with the mass $m_a = fracm_\pi f_\pi F$, where F is the scale of Peccei-Quinn symmetry breaking. Axion couplings to fermions are inversely proportional to F, and its lifetime relative to decay on 2γ is equal to $t_a = frac64\pi F^2 m_a^3$. - Equivalence of right- and left- handed coordinate systems implies the existence of mirror partners of ordinary particles. Mirror particles should not have ordinary gauge interactions and their own mirror interactions should be symmetric to the respective interactions of respective ordinary partners. Then mirror particles, having the same mass spectrum and the same internal mirror couplings as their ordinary partners, are coupled to the ordinary matter by gravity only. - Mirror particles can be included together with the ordinary particles into the unifying GUT. It leads, after the GUT symmetry is broken and the ordinary and mirror sectors, retaining the discrete symmetry between them, are separated, to the existence of Alice strings, cosmic strings, changing the relative mirrority of objects along the closed paths around them. - In superstring models initial mirror symmetry is broken due to combined action of compactification and gauge symmetry breaking, so that shadow matter appears, loosing the discrete symmetry with the ordinary partners. In heterotic string model the initial $E_8 x E_8'$ gauge symmetry, assuming exact symmetry between the ordinary (E_8) and mirror (E_8') worlds in 10 space-time dimensional string model, is reduced after compactification and gauge symmetry breaking to $(broken)E_6 x(broken?)E_8'$ 4-dimensional effective field model with the ordinary matter embraced by $(broken)E_6$ symmetry and the enormously extensive world of shadow particles and their interactions, corresponding to the $(broken?)E_8'$ gauge group. - The Wilson loop mechanism of E_6 symmetry breaking down to the symmetry of standard model implies in the superstring models the existence of at least one new (4th) quark-lepton family and of at least one new $U(1)$ gauge charge. The measured width of Z boson puts lower limit on the possible mass of 4th neutrino $m > 45$GeV. If the new $U(1)$ charge is attributed to the 4th family and is strictly conserved, the 4th neutrino, being the lightest particle of the 4th family, should be absolutely stable. - The mechanism of gauge symmetry breaking in compactification onto Callaby-Yao manifolds or orbifolds, used in superstring models, implies homotopically stable solutions with the mass $M = fracr_c\alpha'$, where r_c is the radius of compactification and α' is the string tension. These objects are sterile relative to gauge interactions and may act on the ordinary matter by gravity only. These and many other examples of the particle zoo, induced by the extensions of the standard model of electroweak and strong interactions, are related to the new phenomena, direct experimental search for which is either very hard or principally impossible. So cosmological effects are important or even unique sources of information on their possible existence.

5. Detectors of the Universe

One may reduce the effect of new particles and fields in the Universe to the two principal possibilities:1) general dynamical influence on the cosmological expansion and 2) specific influence on particular astrophysical processes. In the first case the very presence of hypothetical particles and fields in the Universe, independent on their specific properties, causes some observational effect. In the second case to estimate the expected result some properties of the considered particles and fields should be specified. In the Universe, viewed as particle laboratory, these two types of effects may be compared with integral and differential detectors, used in particle experiment. One can refer to the two widely known cosmological probes of new particles -age of the Universe (the modern total density is restricted by the observational lower bounds on the age of the Universe) and -4He primordial abundance (the total density of the Universe in the period of big bang nucleosynthesis is restricted by the observational upper limit on primordial He abundance, or in more refined approaches by the set of primordial light element abundance constraints) as to the integral detectors, probing the contribution into the cosmological density of any form of the matter, irrespective to its particular properties. In the both cases the only thing we assume on the hypothetical forms of the matter is their existence in our space-time, resulting in their contribution into the total density of the Universe. The same holds true for - the condition of sufficient growth of density fluctuations, following from the existence of the observed large scale structure of the Universe and the observed isotropy of the thermal radiation background. This condition leads to the existence of dust-like stage of (dark) matter dominance sufficiently long to provide the formation of large scale structure from initial density fluctuations, small enough to satisfy the observed level of isotropy of the relic radiation. It excludes the range of parameters of unstable particles (or objects) leading to the dominance of their relativistic decay products in the period of large scale structure formation.

In the latter case one also does not specify the properties or decay modes of the unstable matter. All these methods, being universal, have rather rude sensitivity to the parameters of the hypothetical matter. Only the amount of such matter, comparative to or dominating in the total cosmological density, may be definitely excluded by the integral detectors. More refined and sensitive tools are available, once specific tracers of hypothetical matter are specified.

For stable charge-symmetric species, present in the halo of Galaxy, their weak annihilation, resulting in neutrino-antineutrino, gamma-ray, electron-positron or proton-antiproton production, provides the possibility to exclude the range of respective parameters from - the observed nonthermal electromagnetic backgrounds or observational upper limits on them - the observed gamma ray background - the observed electron-positron background - the data on the cosmic ray fluxes - the restrictions on high energy neutrino cosmic backgrounds which may be viewed as the "experimental" data from differential detectors for the hypothetical processes.

Note, that the EGRET data on galactic gamma background at $E > 1$GeV and the data on underground WIMP searches are consistent with the hypothesis on the existence of stable 4th neutrino with the mass 50GeV (Golubkov et al, 1999). Annihilation of primordial 4th neutrinos and antineutrinos in the halo of our Galaxy should lead to the signature in the spectrum of cosmic positrons, which can be tested in AMS experiment on ISS during the next decade.

For unstable species with the lifetime, smaller, than the age of the Universe, the same types of data trace the respective decay modes, if the Universe is transparent for decay products. For each type of decay product one may fix the redshift, starting from which the Universe is opaque for respective fluxes. Then the data on - the thermal background spectrum distortions and on - the light element abundance from nonequilibrium cosmological nucleosynthesis provides indirect information on the effects of interaction of the fluxes with plasma and radiation in the early Universe. The spectrum of relic radiation may be viewed as "electromagnetic calorimeter" of the early Universe, since any electromagnetic energy release, starting from 10^5 s, induces the distortions of the Planck form of the thermal microwave radiation background spectrum. Light element abundance turns to be even more sensitive probe for inequilibrium processes on the radiation dominance stage, owing to the strong possible change of concentration for the less abundant light elements (D, ^3He, Li, Be, B,...) in nuclear reactions, induced by energetic particle fluxes from the hypothetical sources with comparatively small electromagnetic energy release.

Practically all the above mentioned differential detectors may probe the products of PBH evaporation, so that the restrictions on the sources of respective particle fluxes or effects may be recalculated in the terms of the constraints on the concentration of PBHs with the mass 10^9 - 10^{15} g, evaporating from the 1 s to the present time. Accounting for the possible mechanisms of PBH formation, one may use the data, sensitive to PBH evaporation effects, to probe the hypothetical processes in the very early Universe.

The relative sensitivity of the integral and differential detectors, discussed above, to the hypothetical particles with the relative abundance $\nu = fracnn_\gamma$ (n - concentration of particles and n_γ- concentration of relic photons) and the mass m, causing the respective effects in the period τ, is presented in the review (Khlopov,Chechetkin,1987; Khlopov,1999), where more detailed discussion of various detectors of the Universe and extensive bibliography may be found.

6. Cosmology of horizontal unification

To combine methods of cosmoparticle physics one can consider the approach, trying to incorporate the main properties of elementary particles and the cosmologically relevant parameters, corresponding to the physical mechanisms of inflation, baryosynthesis and dark matter, into the unique quantitatively definite theoretical framework.

Such approach may be illustrated by the model of horizontal unification (see Khlopov, Sakharov,1996 and Refs wherein). It was shown in these studies, that the extension of the standard $SU(2)xU(1)xSU(3)_c$ model of electroweak and strong (QCD) interactions of elementary particles to the gauge symmetry SU(3)H of quark and lepton families provides not only reasonable theoretical description of the established existence of three families of quarks and leptons (ν_e, e, u, d); (ν_μ, μ, c, s); (ν_τ, τ, t, b); but in its realisation turns to be the theoretical framework, incorporating in an unique scheme physical grounds for inflation, baryosynthesis and dark matter. Even at the present level of "minimal" horizontal unification the quantitatively definite choice of the parameters of the model in a result of a combined analysis of its physical, astrophysical and cosmological predictions has lead to reasonable dark matter models of cosmological large scale structure format ion, as well as to quantitatively definite scenario of cosmological evolution from Planck times to the period of galaxy formation and a set of predictions, open for experimental and observational tests.

This model, offering the alternative (horizontal) way to unification, is in no case alternative to the more popular GUT or supersymmetric extensions of the standard model. The internal problems of the minimal horizontal unification imply its further supersymmetric and GUT extensions, which are expected to give better consistency with the observations for its astrophysical and cosmological predictions. But even in the present form the model reflects the main principles of cosmoparticle physics. On the base of local gauge model with spontaneous symmetry breaking it provides the phenomenology of world system, putting together practically all the main known particle properties and the main necessary cosmological parameters, related to the hidden sector of particle theory. It offers the quantitatively definite correspondence between fundamental cosmological parameters (form of inflaton potential, lepton number violation, mass, spectrum and lifetime of dark matter particles and fields), astr ophysical effects (rate of stellar archion emittion, contributing significantly stellar energy losses and dynamics of stellar collapse) and particle properties (see-saw mechanism of mass generation, hierachy of masses and mixings of quark and lepton families, Majorana mass ratio of neutrinos, rates of archion decays, double neutrinoless beta decays). Finally, the amount of free parameters of the model turns to be much less, than the amount of its signatures in particle processes, astrophysics and cosmology, thus providing its definite test and exhibiting its completeness.

So, the model illustrates the might of cosmoparticle approach. Its fundamental scale of horizontal symmetry breaking is *a priori* unknown and corresponds to the hidden sector of particle theory, but complex analysis of the set of its physical, astrophysical and cosmological predictions makes it possible to fix the value of this scale in two rather narrow windows (around 10^6GeV and around 10^{10}GeV). The second solution, corresponding to higher energy scale, seem to reproduce all the main features of widely assumed as standard cosmological scenario with inflation, baryosynthesis and cold (axionic) dark matter. The practical realisation of such scenario, which in no case reflects complete physical basis, shows, that even the most simple reduced csmological scenario does contain some additional elements (e.g. post inflational dust-like stage, on which primordial black hole (PBH) formation is possible with successive PBH evaporation at RD stage after primordial nucleosyntheis, formation of primordial percollational structure of archioles etc). This example favours the conclusion, that in *no* cases new cosmological elements, based on the hypothetical effects of particle physics, are reduced to inflation, baryosynthesis and dark matter *only*.

The development of cosmoparticle physics will lead to great astronomical and physical discoveries. Such exciting phenomena as the existence of thousands antimatter stars in our Galaxy, of the 4th stable massive neutrino, of matter or shadow matter can find experimental and observational proofs even in the next decade. One can expect that the future Millennium will uncover before the fundamental science the dark side of the Universe and its hidden physical mechanism. On this way the Gamov's idea of the Universe governed by the laws of fundamental physics will find proper realisation and physical content.

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References

Battiston R.: 1999. *Gravitation and Cosmology, Supplement*, bf 5, 54.

Belotsky K.M. et al.: 1999, *Gravitation and Cosmology, Supplement.*, bf 5, 47.

Chechetkin V.M., Khlopov M.Yu., Sapozhnikov M.G.: 1982, *Riv. Nuovo Cimento*, **5**,N-10.

Comelli D., Pietroni M., Riotto A.: 1994, *Nucl. Phys.*, **B412**, 441.

Dolgov A.D.,Illarionov A.F., Kardashev N.S., Novikov I.D.: 1987, *ZhETF*, **94**, 1.

Golubkov Yu.A., Konoplich R.V., Mignani R., Fargion D., Khlopov M.Yu.: 1999, *JETP Lett.*, **69**, 434.

Guth A.: 1981, *Phys. Rev.*, **D23**, 347.

Khlopov M.Yu., Chechetkin V.M.: 1987, *Sov. J. Part. Nucl.*, **18**, 267.

Khlopov M.Yu., Sakharov A.S.: 1996, *Proc. Cosmion-94*, Eds. M.Yu.Khlopov et al., Editions Frontieres, 273.

Khlopov M.Yu.: 1992 *Sov. J. Nucl. Phys.*, **55**,765.

Khlopov M.Yu.: 1996, *Proc. Cosmion-94*, Eds. M.Yu.Khlopov et al., Editions Frontieres, 67.

Khlopov M.Yu.: 1998, *Gravitation and Cosmology*, **4**, 69.

Khlopov M.Yu.: 1999, *Cosmoparticle physics*, World Scientific.

Kuzmin V.A.: 1970, *JETP Lett.*, **12**, 335.

Sakharov A.D.: 1967, *JETP Lett.*, **5**, 17.

Schramm D.N., Copi C.: 1996, *Proc. Cosmion-94*, Eds. M.Yu.Khlopov et al., Editions Frontieres, 77.

Zeldovich Ya.B., Novikov I.D.: 1975, *Structure and evolution of the Universe*, Nauka, M.