PHYSICS OF PRIMORDIAL UNIVERSE

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The physical basis of the modern cosmological inflationary models with baryosynthesis and nonbaryonic dark matter and energy implies such predictions of particle theory, that, in turn, apply to cosmology for their test. It makes physics of early Universe ambiguous and particle model dependent. The study of modern cosmology is inevitably linked with the probe for the new physics, underlying it. The particle model dependent phenomena, such as unstable dark matter, primordial black holes, strong primordial inhomogeneities, can play important role in revealing the true physical cosmology. Such phenomena, having serious physical grounds and leading to new nontrivial cosmological scenarious, should be taken into account in the data analysis of observational cosmology.

1 Cosmology of Particle Models

In the modern cosmology the expansion of the Universe and its initial conditions is related to the process of inflation. The global properties of the Universe as well as the origin of its large scale structure are the result of this process. The matter content of the modern Universe is also originated from the physical processes: the baryon density is the result of baryosynthesis and the nonbaryonic dark matter represents the relic species of physics of the hidden sector of particle theory. Physics, underlying inflation, baryosynthesis and dark matter, is referred to the extensions of the standard model, and the variety of such extensions makes the whole picture in general ambiguous. However, in the framework of each particular physical realization of inflationary model with baryosynthesis and dark matter the corresponding model dependent cosmological scenario can be specified in all the details. In such scenario the main stages of cosmological evolution, the structure and the physical content of the Universe reflect the structure of the underlying physical model. The latter should include with necessity the standard model, describing the properties of baryonic matter, and its extensions, responsible for inflation, baryosynthesis and dark matter. In no case the cosmological impact of such extensions is reduced to reproduction of these three phenomena only. The nontrivial path of cosmological evolution, specific for each particular realization of inflational model with baryosynthesis and nonbaryonic dark matter, always contains some additional model dependent cosmologically viable predictions, which can be confronted with astrophysical data (see[1] for review).

2 Cosmophenomenology of New Physics in Early Universe

To study the imprints of new physics in astrophysical data the forms and means in which new physics leaves such imprints should be specified. So, the important tool in linking the cosmological predictions of particle theory to observational data is the *Cosmophenomenology* of new physics[2]. It studies the possible hypothetical forms of new physics, which may appear as cosmological consequences of particle theory, and their properties, which can result in observable effects.

The simplest primordial form of new physics is the gas of new stable massive particles, originated from early Universe. For particles with the mass m, at high temperature $T > m$ the equilibrium condition, $n \cdot \sigma v \cdot t > 1$ is valid, if their annihilation cross section $\sigma > 1/(m m_{Pl})$ is sufficiently large to establish the equilibrium. At $T < m$ such particles go out of equilibrium and their relative concentration freezes out. More weakly interacting species decouple from plasma and radiation at $T > m$, when $n \cdot \sigma v \cdot t \sim 1$, i.e. at $T_{dec} \sim (\sigma m_{Pl})^{-1}$. The maximal temperature, which is reached in inflationary Universe, is the reheating temperature, T_r, after inflation. So, the very weakly interacting particles with the annihilation cross section $\sigma < 1/(T_r m_{Pl})$, as well as very heavy particles with the mass $m \gg T_r$ can not be in thermal equilibrium, and the detailed mechanism of their production should be considered to calculate their primordial abundance.

Decaying particles with the lifetime τ, exceeding the age of the Universe, t_U, $\tau > t_U$, can be treated as stable. They form the modern multi-component dark matter, being its dominant and sub-dominant components.

Primordial unstable particles with the lifetime, less than the age of the Universe, $\tau < t_U$, can not survive to the present time. But, if their lifetime is sufficiently large to satisfy the condition $\tau \gg (m_{Pl}/m) \cdot (1/m)$, their existence in early Universe can lead to direct or indirect traces. Cosmological flux of decay products contributing into the cosmic and gamma ray backgrounds represents the direct trace of unstable particles. If the decay products do not survive to the present time their interaction with matter and radiation can cause indirect trace in the light element abundance or in the fluctuations of thermal radiation. If the particle lifetime is much less than 1s the multi-step indirect traces are possible, provided that particles dominate in the Universe before their decay. On the dust-like stage of their dominance black hole formation takes place, and the spectrum of such primordial black holes traces the particle properties (mass, frozen concentration, lifetime)[4]. The particle decay in the end of dust like stage influences the baryon asymmetry of the Universe. In any way cosmophenomenoLOGICAL chains link the predicted properties of even unstable new particles to the effects accessible in astronomical observations. Such effects may be important in the analysis of the observational data.

So, the only direct evidence for the accelerated expansion of the modern Universe comes from the distant SN I data. The data on the cosmic microwave background (CMB) radiation and large scale structure (LSS) evolution (see e.g. [5]) prove in fact the existence of homogeneously distributed dark energy and the slowing down of LSS evolution at $z \leq 3$. Homogeneous negative pressure medium (Λ-term or quintessence) leads to *relative* slowing down of LSS evolution due to acceleration of cosmological expansion. However, both homogeneous component of dark matter and slowing down of LSS evolution naturally follow from the models of Unstable Dark Matter (UDM) (see[1] for review), in which the structure is formed by unstable weakly interacting particles. The weakly interacting decay products are distributed homogeneously. The loss of the most part of dark matter after decay slows down the LSS evolution. The dominantly invisible decay products can contain small ionizing component[3]. Thus, UDM effects will deserve attention, even if the accelerated expansion is proved.

The parameters of new stable and metastable particles are determined by the pattern of particle symmetry breaking. This pattern is reflected in the succession of phase transitions in the early Universe. The phase transitions of the first order proceed through the bubble nucleation, which can result in black hole formation. The phase transitions of the second order can lead to formation of topological defects, such as walls, string or monopoles. The observational data put severe constraints on magnetic monopole and cosmic wall production, as well as on the parameters of cosmic strings. The succession of phase transitions can change the structure of cosmological defects. The more complicated forms, such as walls-surrounded-by-strings can appear. Such structures can be unstable, but their existence can lead the trace in the nonhomogeneous distribution of dark matter and in large scale correlations in the nonhomogeneous dark matter structures, such as *archioles*[6].

3 Strong Primordial Inhomogeneities

The standard approach to LSS formation considers the evolution of small initial fluctuations only. Such approach seems to be supported by the homogeneity and isotropy of the Universe. However, the amplitude of density fluctuations $\delta \equiv \delta\varrho/\varrho$ measures the level of inhomogeneity relative to the total density, ϱ. The partial amplitude $\delta_i \equiv \delta\varrho_i/\varrho_i$ measures the level of fluctuations within a particular component with density ϱ_i, contributing into the total density $\varrho = \sum_i \varrho_i$. The case $\delta_i \geq 1$ within the considered i-th component corresponds to its strong inhomogeneity. Strong inhomogeneity is compatible with the smallness of total density fluctuations, if the contribution of inhomogeneous component into the total density is small: $\varrho_i \ll \varrho$, so that $\delta \ll 1$.

The large scale correlations in topological defects and their imprints in primordial inhomogeneities is the indirect effect of inflation, if phase transitions take place after reheating of the Universe. Inflation provides in this case the equal conditions of phase transition, taking place in causally disconnected regions.

If the phase transitions take place on inflational stage new forms of primordial large scale correlations appear. The example of global U(1) symmetry, broken spontaneously in the period of inflation and successively broken explicitly after reheating, was recently considered in[7]. In this model, spontaneous U(1) symmetry breaking at inflational stage is induced by the vacuum expectation value $\langle\psi\rangle = f$ of a complex scalar field $\Psi = \psi \exp{(i\theta)}$, having also explicit symmetry breaking term in its potential $V_{eb} = \Lambda^4(1 - \cos\theta)$. The latter is negligible in the period of inflation, if $f \gg \Lambda$, so that there appears a valley relative to values of phase in the field potential in this period. Fluctuations of the phase θ along this valley, being of the order of $\Delta\theta \sim H/(2\pi f)$ (here H is the Hubble parameter at inflational stage) change in the course of inflation its initial value within the regions of smaller size. Owing to such fluctuations, for the fixed value of θ_{60} in the period of inflation with *e-folding* $N = 60$ corresponding to the part of the Universe within the modern cosmological horizon, strong deviations from this value appear at smaller scales, corresponding to later periods of inflation with $N < 60$. If $\theta_{60} < \pi$, the fluctuations can move the value of θ_N to $\theta_N > \pi$ in some regions of the Universe. After reheating, when the Universe cools down to temperature $T = \Lambda$ the phase transition to the true vacuum states, corresponding to the minima of V_{eb} takes place. For $\theta_N < \pi$ the minimum of V_{eb} is reached at $\theta_{vac} = 0$, whereas in the regions with $\theta_N > \pi$ the true vacuum state corresponds to $\theta_{vac} = 2\pi$. For $\theta_{60} < \pi$ in the bulk of the volume within the modern cosmological horizon $\theta_{vac} = 0$. However, within this volume there appear regions with $\theta_{vac} = 2\pi$. These regions are surrounded by massive domain walls, formed at the border between the two vacua. Since regions with $\theta_{vac} = 2\pi$ are confined, the domain walls are closed. After their size equals the horizon, closed walls can collapse into black holes. The minimal mass of such black hole is determined by the condition that it's Schwarzschild radius, $r_g = 2GM/c^2$ exceeds the width of the wall, $l \sim f/\Lambda^2$, and it is given by $M_{min} \sim f(m_{Pl}/\Lambda)^2$. The maximal mass is determined by the mass of the wall, corresponding to the earliest region $\theta_N > \pi$, appeared at inflational stage. This mechanism can lead to formation of primordial black holes of a whatever large mass (up to the mass of AGNs [8]). Such black holes appear in the form of primordial black hole clusters, exhibiting fractal distribution in space [7]. It can shed new light on the problem of galaxy formation.

Primordial strong inhomogeneities can also appear in the baryon charge distribution. The appearance of antibaryon domains in the baryon asymmetrical Universe, reflecting the inhomogeneity of baryosynthesis, is the profound signature of such strong inhomogeneity [9]. On the example of the model of spontaneous baryosynthesis (see [10] for review) the possibility for existence of antimatter domains, surviving to the present time in inflationary Universe with inhomogeneous baryosynthesis was revealed in [11]. Evolution of sufficiently dense antimatter domains can lead to formation of antimatter globular clusters [12]. The existence of such cluster in the halo of our Galaxy should lead to the pollution of the galactic halo by antiprotons. Their annihilation can reproduce [13] the observed galactic gamma background in the range tens-hundreds MeV. The prediction of antihelium component of cosmic rays [14], accessible to future searches for cosmic ray antinuclei in PAMELA and AMS II experiments, as well as of antimatter meteorites [15] provides the direct experimental test for this hypothesis.

So the primordial strong inhomogeneities in the distribution of total, dark matter and baryon density in the Universe is the new important phenomenon of cosmological models, based on particle models with hierarchy of symmetry breaking.

To conclude, the physical cosmology inevitably implies a set of new nontrivial phenomena. Unstable dark matter, primordial black holes and inhomogeneous structures, antimatter domains in baryon asymmetrical Universe - are the examples of physically motivated cosmological signatures of new physics, deserving attention in the data analysis of precision cosmology.

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