The development of cross disciplinary studies in cosmology and particle physics on the platform of a Scientific-Educational complex of Virtual Institute of Astroparticle physics (VIA)

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Abstract. The overview of the main problems and methods of cosmoparticle physics, studying fundamental relationship of micro- and macro-worlds, is accompanied by the demonstration of the facility of Virtual Institute of Astroparticle physics (VIA) activity as a well proven platform for scientific collaborative work and education at distance.

1. Introduction

Cosmoparticle physics \cite{1, 2, 3, 4, 5} studies the fundamental basis and mutual relationship between micro-and macro-worlds in the proper combination of physical, astrophysical and cosmological signatures. It originated from the modern trend of particle physics to go beyond the Standard model and from the development of the modern cosmology, implying new physics to explain inflation, baryosynthesis and dark matter and energy - its basic elements, proved by observations but having no grounds in the physics of the Standard model. Here we concentrate on some aspects of this relationship, which arise in the problem of cosmological Dark Matter (DM).

Extensions of the standard model imply new symmetries and new particle states. The respective symmetry breaking induces new fundamental physical scales in particle theory. In particle theory Noether’s theorem relates the exact symmetry to conservation of respective charge. If the symmetry is strict, the charge is strictly conserved. The lightest particle, bearing this charge, is stable. It gives rise to the fundamental relationship between dark matter candidates and particle symmetry beyond the Standard model.

If the symmetry is broken, the mechanism of the symmetry breaking implies restoration of the symmetry at high temperatures and densities. Such high temperatures and densities should have naturally arisen at the early stages of cosmological evolution. It makes Big Bang Universe natural laboratory of particle physics, not only due to possibility of creation of hypothetical
particles in the early Universe, but also owing to reflection of the hierarchy of particle symmetry breaking in cosmological phase transitions.

2. Cosmoparticle physics of dark matter

According to the modern cosmology, the dark matter corresponds to \( \sim 25\% \) of the total cosmological density. This form of matter (see e.g. [5, 6] for review and reference) should be stable and saturate the measured dark matter density. Formation of the Large Scale Structure of the Universe from small initial density fluctuations is one of the most important reasons for the nonbaryonic nature of the dark matter that is decoupled from matter and radiation at least before the beginning of matter dominated stage and provides the effective growth of these fluctuations before recombination. The easiest way to satisfy these conditions is to assume that the dark matter candidates from the physics beyond the Standard model are Weakly Interacting massive particles (WIMPs) (see [6] for a review). However, problems of direct and indirect dark matter searches may imply more sophisticated solutions for this problem.

On the other hand, the initial density fluctuations, coming from the very early Universe are also originated from physics beyond the Standard model. It links the primordial seeds of galaxy formation to effects of particle theory at very high energies.

2.1. Dark matter and physics of very early Universe

2.1.1. Charge symmetric case. WIMPs

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 \( \sigma > 1/(mm_{Pl}) \) is sufficiently large to establish the equilibrium. At \( T < m \) such particles go out of equilibrium and their relative concentration freezes out. This is the main idea of calculation of primordial abundance for Weakly Interacting Massive Particles (WIMPs).

If ordinary particles are among the products of WIMP annihilation, even their small fraction can annihilate in the Galaxy causing significant effect in cosmic rays and gamma background. This effect, first revealed in [7] and then proved for even subdominant fraction of annihilating dark matter in [8], is now in the basis of indirect dark matter searches in cosmic rays [9].

The process of WIMP annihilation to ordinary particles, considered in \( t \) channel, determines their scattering cross section on ordinary particles and thus relates the primordial abundance of WIMPs to their scattering rate in the ordinary matter. Forming nonluminous massive halo of our Galaxy, WIMPs can penetrate the terrestrial matter and scatter on nuclei in underground detectors. The strategy of direct WIMP searches implies detection of recoil nuclei from this scattering.

Weak interaction of dark matter particles with matter can be directly detected by recoil caused by these particles in the matter. This idea was first proposed for massive neutrinos in the diploma work by Zeldovich’s pupil V. Shvartsman in 1969 and was published in [11]. Direct search of weakly interactive massive particles (WIMPs) is now under way (see [12] for review and references) giving controversial results, what may find a nontrivial explanation by dark atoms.

The process inverse to annihilation of WIMPs corresponds to their production in collisions of ordinary particles. It should lead to effects of missing mass and energy-momentum, being the challenge for experimental search for production of dark matter candidates at accelerators, e.g. at the LHC.

2.1.2. Charge asymmetry of dark matter

The fact that particles are not absolutely stable means that the corresponding charge is not strictly conserved and generation particle charge asymmetry is possible, as it is assumed for ordinary baryonic matter. At sufficiently strong particle annihilation cross section excessive particles (antiparticles) can dominate in the relic density, leaving exponentially small admixture of their antiparticles (particles) in the same way.
as primordial excessive baryons dominate over antibaryons in baryon asymmetric Universe. In this case *Asymmetric dark matter* doesn’t lead to significant effect of particle annihilation in the modern Universe and can be searched for either directly in underground detectors or indirectly by effects of decay or condensation and structural transformations of e.g. neutron stars (see [10] for recent review and references).

### 2.2. Dark atoms

#### 2.2.1. Charged stable relics

**Dark atoms** A possibility that new stable charged leptons and quarks can exist was proposed in Glashow’s tera-helium solution for dark matter [13]. This solution came from the assumed million times heavier partners of quarks and charged leptons, among which tera-E-electron and tera-U quark were sufficiently stable to form neutral [(UUU)EE] tera-helium ”atoms” that behaved like WIMPs. The main problem for this solution was to suppress the abundance of positively charged species bound with ordinary electrons, which behave as anomalous isotopes of hydrogen or helium. This problem turned to be unresolvable [14], since the model [13] predicted stable tera-electrons $E^-\bar{U}$ with charge -1. As soon as primordial helium is formed in the Standard Big Bang Nucleosynthesis (SBBN) it captures all the free $E^-$ in positively charged $(\text{He}E)^+$ ion, preventing any further suppression of positively charged species. Therefore, in order to avoid anomalous isotopes overproduction, stable particles with charge -1 (and corresponding antiparticles) should be absent, so that stable negatively charged particles should have charge -2 only.

#### 2.2.2. Charged dark atoms’ constituents

Elementary particle frames for heavy stable -2 charged species are provided by: (a) stable ”antibaryons” $\bar{U}\bar{U}\bar{U}$ formed by anti-U quark of fourth generation (b) AC-leptons, predicted in the extension of standard model, based on the approach of almost-commutative geometry; (c) Technileptons and anti-technibaryons in the framework of walking technicolor models (WTC). (see [6] for review and references). Since all these models also predict corresponding +2 charge antiparticles, cosmological scenario should provide mechanism of their suppression, what can naturally take place in the asymmetric case, corresponding to excess of -2 charge species, $O^{--}$. Then their positively charged antiparticles can effectively annihilate in the early Universe.

If new stable species belong to non-trivial representations of electroweak SU(2) group, sphaleron transitions at high temperatures can provide the relationship between baryon asymmetry and excess of -2 charge stable species, as it was demonstrated in the case of WTC in [15].

#### 2.2.3. Dark atoms cosmology

A cosmological model of O-helium dark matter can explain the puzzles of direct dark-matter searches. The proposed explanation is based on a specific mechanism for low-energy binding of OHe with nuclei. Within the uncertainty of nuclear physics parameters there exists a range for which the OHe binding energy with sodium is in the interval 2-4 keV. The annual modulation in the radiative capture of OHe to this bound state leads to the corresponding energy release observed as an ionization signal in DAMA/NaI and DAMA/LIBRA. An interesting feature of this explanation is the conclusion that the ionization signal may be absent in detectors containing light (e.g. $^3\text{He}$) or heavy (e.g. Xe) elements. Therefore a test of the results of the DAMA/NaI and DAMA/LIBRA experiments by other experimental groups can become a very non-trivial task.

The advantages of the OHe Warmer-than-Cold-dark-matter scenario is that it is minimally related to the parameters of new physics and is dominantly based on the effects of known atomic and nuclear physics. These effects need proper quantitative description of OHe interaction with matter and its development confronted with the experimental data will provide the complete test of the composite dark matter model. The model can explain the observed excess of low
and high energy positrons in the Galaxy for the fixed values of $O^{--}$ masses around 1 TeV. It challenges search for stable double charged particles at accelerators and cosmic rays as direct experimental probe for charged constituents of dark atoms of dark matter.

3. VIA platform for cosmoparticle physics

The development of cosmoparticle physics implies cross disciplinary studies and Virtual Institute of Astroparticle Physics (VIA) [16] was organized as a platform for this development. The activity of the Institute takes place on its website (see [17] for the latest review) in a form of regular weekly videoconferences with VIA lectures, covering all the theoretical and experimental activities in astroparticle physics and related topics. The library of records of these lectures, talks and their presentations is accomplished by multi-lingual Forum.

One of the interesting forms of VIA activity is the educational work at distance. For the last six years M.Khlopov’s MEPhI course ”Introduction to cosmoparticle physics” is given in the form of VIA videoconferences and the records of these lectures and their presentations are put in the corresponding directory of the Forum [17]. Having attended the VIA course of lectures in order to be admitted to exam students should put on Forum a post with their small thesis. Professor’s comments and proposed corrections are put in a Post reply so that students should continuously present on Forum improved versions of work until it is accepted as satisfactory. Then they are admitted to pass their exam. The record of videoconference with their oral exam is also put in the corresponding directory of Forum. Such procedure provides completely transparent way of evaluation of students’ knowledge. Since 2014 the second part of this course is used for an application of VIA system as a possible supplementary tool for Massive Online Open Courses (MOOC) activity [17]. In the context of MOOC VIA facility can be used for individual online work with advanced students.

The experience gained in MEPhI in the use of VIA facility makes natural appearance of VIA Session at the present conference.

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