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Nuclear Data for Dark Matter Astrophysics

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Introduction

The convergence of the frontiers of our knowledge in micro and macro Worlds lead to the following wrong circle of problems: *The theory of the Universe is based on the predictions of particle theory that need cosmology for their test*. Cosmoparticle physics [1-4] offers the way out of this wrong circle. It studies the fundamental basis and mutual relationship between micro-and macro-worlds in the proper combination of physical, astrophysical and cosmological signatures. The important aspects of this relationship arise in the problem of cosmological dark matter (DM), which sheds new light on the still unexplored features of nuclear physics.

According to the modern cosmology, the dark matter, corresponding to ~25% of the total cosmological density, is nonbaryonic and consists of new stable forms of matter. These forms of matter [3-8] should be stable, saturate the measured dark matter density and decouple from plasma and radiation at least before the beginning of matter dominated stage. The easiest way to satisfy these conditions is to involve neutral elementary weakly interacting particles.

Even the simplest and the most popular dark matter candidates – weakly interacting massive particles (WIMP) [3-8] exhibit a set of nontrivial links between their astrophysics and nuclear data.

The process of WIMP annihilation to ordinary particles 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 annihilate in it to ordinary particles with a significant impact on in the spectrum of cosmic rays and gamma radiation, what is used in the methods of indirect searches for dark matter. 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 [9]. 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. However WIMPs are not the only particle physics solution for the dark matter problem and more evolved models of the physical nature of dark matter are possible. The list of dark matter candidates extends to both strongly and super weakly interacting particles, which are elusive for direct or indirect methods of WIMP searches. It implies more nontrivial methods to study their properties, which involve all the possible aspects of dark matter physics.

The example of super weakly interacting graviton can illustrate the impact of nuclear data in the studies of cosmological consequences of particle theory. Gravitinos are expected to be present in all local supersymmetric models, which are regarded as the more natural extensions of the standard model of high energy physics [4,8] and provide WIMP-like Dark matter candidates like neutralino.

In the framework of minimal Supergravity (mSUGRA), the gravitino mass is, by construction, expected to lie around the electroweak scale, *i.e.* in the 100 GeV range. In this case, the gravitino is metastable and decays after nucleosynthesis, leading to important modifications of the nucleosynthesis paradigm. High energy products of gravitino decays interact with nuclei of the primordial plasma and give rise to cascades of non-equilibrium nuclear processes In particular, the antiprotons produced by the fragmentation of gluons emitted by decaying gravitinos are a source of non-equilibrium light nuclei resulting from collisions of those antiprotons on equilibrium nuclei [10,11]. Then, 6Li, 7Li and 7Be nuclei are produced by the interactions of the non-equilibrium nuclear flux with 4He equilibrium nuclei.

To compare these predictions with the observational data on the light element abundance the precise in formation on the particle and nuclear interactions with nuclei is needed. Therefore this approach, supported by its successive development.

Reveals the importance of obtaining these nuclear data as the completion of the missed link in the logical chain, by which cosmological consequences of particle theory are related to their astrophysical probes.

Direct searches for dark matter have produced surprising results. Since the DAMA collaboration observed a signal, several other collaborations 2 seem to confirm an observation, but many others clearly rule out any detection.

The current experimental situation is reviewed in this apparent contradiction comes from the analysis of the data under the assumption that nuclear recoils are the source of the signal.

Starting from 2006 it was proposed that the signal may be due to a different source: if dark matter can bind to normal matter, the observations could come from radiative capture of thermalized dark matter, and could depend on the detector composition and temperature. This scenario naturally comes from the consideration of composite dark matter.

Indeed, one can imagine that dark matter is the result of the existence of heavy negatively charged particles that bind to primordial nuclei.

New particles with electric charge and/or strong interaction can form anomalous atoms and be present in the ordinary matter as anomalous isotopes. Therefore, stringent upper limits on anomalous isotopes, especially, on anomalous hydrogen put severe constraints

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on the existence of new stable charged particles. 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.

Elementary particle frames for heavy stable -2 O^{--}charged species are provided by several models (see e.g. for review and references). In all these models $O^{--}$are either leptons or like ($\bar{U}\bar{U}\bar{U}$) clusters of heavy $\bar{U}$ quarks have strongly suppressed hadronic interaction. Just after Big Bang Nucleosynthesis, when primordial helium is produced, all the O^{--} are bound with helium nuclei in atom-like O-helium state, in which heavy lepton-like negatively charged core is surrounded by a nuclear interacting helium shell. Collisions of such atoms in the center of Galaxy can lead to their excitation with successive de-excitation by emission of electron-positron pairs, what can explain the observed excess in positronium annihilation line in the galactic bulge.

O-helium, being a particle with screened electric charge, can catalyze nuclear transformations, which can influence primordial light element abundance and cause primordial heavy element formation. It is especially important for quantitative estimation of role of O-He in Big Bang nucleosynthesis and in stellar evolution. These effects need a special detailed and complicated study of OHe nuclear physics and this work is under way.

Nuclear physics data are unavoidable in searches for rare processes, like double neutrinoless beta decay, that may be indirectly related the problems of dark matter physics. These types of relationships extends the field of exploration to the data, which are not directly involved in the studies of dark matter astrophysics, but provide an important information on new 3 physics, which determines the dark matter properties.

Indirect searches for dark matter involve various effects of dark matter interaction with the matter of stars and planets, in which nuclear data are necessary.

To conclude, even a brief sketch of possible links of dark matter physics to the nuclear data shows how large may be the field of such studies, what appeals to its extensive and through investigation in all the nontrivial aspects of these links. A JAAT special issue" Nuclear data for Dark Matter Astrophysics" may provide a good platform for these studies.

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