National Research Nuclear University “MEPhI”

Department 40 (Physics of Elementary Particles)

Report of the course “Introduction into MicroCosmophysics”

**Anomalous Isotopes as a Probe for**

**New Stable Forms of Matter**

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7. **Introduction.**

It is known that Standard Big Bang Nucleosynthesis gives rise to formation of light elements only and its theory predicts negligible pre-galactic abundance of elements, heavier than lithium. This point can change drastically, if there exist stable charged leptons and/or quarks. Several elementary particle frames for heavy stable charged particles were considered:

1. A heavy quark and heavy neutral lepton (neutrino with mass above half the Z-Boson mass) of fourth generation, which can avoid experimental constraints and form composite dark matter species [1];
2. A Glashow’s “Sinister” heavy tera-quark U and tera-electron E, which can form a tower of tera-hadronic and tera-atomic bound states with “tera-helium atoms” (UUUEE) considered as dominant dark matter [2];
3. AC-leptons, predicted in the extension of standard model, based on the approach of almost-commutative geometry, can form evanescent AC-atoms, playing the role of dark matter [3];
4. Finally, it was shown in [4], that an elegant solution is possible in the framework of walking Technicolor models and can be realized without an *ad hoc* assumption on charged particle excess, made in the approaches (a)-(c) [5].

In all these models, predicting stable charged particles, the particles escape experimental discovery, because they are hidden in elusive atoms, maintaining dark matter of the modern Universe. It offers new solution for the physical nature of the cosmological dark matter. Influence on the primordial chemical composition and appearance of primordial heavy elements is an inevitable consequence of this solution. Indeed, it turned out that the necessary condition for the considered scenario, avoiding anomalous isotopes overproduction, is absence of stable particles with charge -1, so that stable negatively charged particles should only have charge -2. After it is formed in Big Bang Nucleosynthesis, $^{++}$ screens the $A^{--}$charged particles in composite ($^{++}A^{--}$) O-helium “atoms”. These neutral primordial nuclear interacting objects contribute the modern dark matter density and play the role of a nontrivial form of strongly interacting dark matter.

The active influence of this type of dark matter on nuclear transformations seems to be incompatible with the expected dark matter properties. However, it turns out that the considered scenario is not easily ruled out and challenges the experimental search for various forms of O-helium and its charged constituents.

1. **Formation of O-helium.**

In the Big Bang Nucleosynthesis, $$ is formed with an abundance $r\_{He}$ = 0.1$r\_{B}$ = 8·$10^{-12}$ and, being in excess, binds all the negatively charged technispecies into atom-like systems.

At a temperature T < $I\_{0}$ = $Z\_{TC}^{2}Z\_{He}^{2}α^{2}m\_{He}$/2 ~ 1.6MeV, where α is the fine structure constant, and $Z\_{TC}^{}$ = −2 stands for the electric charge of $\overbar{UU}$ and/or of ζ, the reaction



and/or



can take place. In these reactions neutral techni-O-helium “atoms” (tOHe) are produced. The size of these “atoms” is



Virtually all the free ($\overbar{UU}$) and/or ζ (which will be further denoted by $A^{--}$) are trapped by helium and their remaining abundance becomes exponentially small.

For particles $Q^{-}$ with charge −1, as for tera-electrons in the sinister model, $$ trapping results in the formation of a positively charged ion $(^{++}Q^{-})^{+}$, result in dramatic over-production of anomalous hydrogen. Therefore, only the choice of −2 electric charge for stable techniparticles makes it possible to avoid this problem. In this case, 4He trapping leads to the formation of neutral techni-O-helium *techni-O-helium “atoms”* ($^{++}A^{--}$).

Binding of various types of such particles with $$ results in different forms of O-helium atoms: O-helium, OLe-helium, ANO-helium or techni-O-helium. However, all these different forms of O-helium have the same size (3), the same cross section for interaction with baryonic matter and play the same role in nuclear transformations.

1. **Primordial heavy elements from O-helium catalysis.**

O-helium looks like an α particle with a shielded electric charge. It can closely approach nuclei due to the absence of a Coulomb barrier. Because of this in the presence of O-helium the character of Standard Big Bang Nucleosynthesis (SBBN) processes should change drastically. However, it might not lead to immediate contradictions with the observational data.

The interaction of the $$ component of ($^{++}A^{--}$) with a $$ nucleus can lead to a nuclear transformation due to the reaction



provided that the masses of the initial and final nuclei satisfy the energy condition



where $I\_{0}$ = 1.6MeV is the binding energy of O-helium and M(4, 2) is the mass of the $$ nucleus.

This condition is not valid for stable nuclei participating in reactions of the SBBN. However, tritium $$, which is also formed in SBBN with abundance $$/H ~ $10^{-7}$ satisfies this condition and can react with O-helium, forming $$ and opening the path of successive O-helium catalyzed transformations to heavy nuclei. This effect might strongly influence the chemical evolution of matter on the pre-galactic stage and needs a self-consistent consideration within the Big Bang Nucleosynthesis network.

• On the path of reactions (4), the final nucleus can be formed in the excited (α,M(A,Z)) state, which can rapidly experience an α- decay, giving rise to O-helium regeneration and to an effective quasi-elastic process of ($^{++}A^{--}$)-nucleus scattering. It leads to a possible suppression of the O-helium catalysis of nuclear transformations .

• The path of reactions (4) does not stop on $$ but goes further through $$, $$, $$, ... along the table of the chemical elements.

• The cross section of reactions (4) grows with the mass of the nucleus, making the formation of the heavier elements more probable and moving the main output away from a potentially dangerous Li and B overproduction.

 Charged massive particles Big Bang Nucleosynthesis (BBN), studying the influence of unstable negatively charged massive particles on BBN. Bound states of metastable singly charged particle $X^{-}$ with nuclei can catalyze formation of lithium and even elements with A > 8. The important difference of SBBN considered in these papers, from our approach, is that singly charged particles $X^{-}$ with charge −1 do not screen the +2 charge of He in a $(HeX)^{+}$ ion-like bound system, and the Coulomb barrier of the $(HeX)^{+}$ ion can strongly hamper the path for the creation of heavy isotopes.

1. **Direct search for O-helium.**

In underground detectors, tOHe “atoms” are slowed down to thermal energies and give rise to energy transfer ~ 2.5·$10^{-3}$ eVA/S2, far below the threshold for direct dark matter detection. It makes this form of dark matter insensitive to the CDMS constraints. However, tOHe induced nuclear transformation can result in observable effects.

Therefore, a special strategy of such a search is needed, that can exploit sensitive dark matter detectors on the ground or in space. In particular, as it was revealed in [48], a few g of superfluid $$ detector, situated in groundbased laboratory can be used to put constraints on the in-falling O-helium flux from the galactic halo.

**References:**

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**Used Articles:**

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2. M. Yu. Khlopov, A.G. Mayorov, E.Yu. Soldatov, “Dark Atoms of the Universe: towards OHe nuclear physics” arXiv:1011.4586v1 [astro-ph.CO]
3. M. Y. Khlopov, “Dark Atoms of Dark Matter from New Stable Quarks and Leptons” arXiv:1012.5756v1 [astro-ph.CO]