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Astrophysical aspects of multiple fragmentation of nuclei in nuclear emulsion

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The BECQUEREL experiment is aimed at solving topical problems in nuclear clustering physics [1]. The used method of nuclear track emulsion (NTE) makes it possible, due to its unique sensitivity and spatial resolution, to study in a unified approach multiple final states arising in dissociation of relativistic nuclei. The ideas about nuclear clustering obtained in high-energy physics are important for applications in nuclear astrophysics, cosmic ray physics, nuclear medicine, and perhaps even nuclear geology. Currently, a research focus is on the theoretical concept of alpha particle Bose-Einstein condensate (αBEC) - the ultra cold state of several S-wave alpha particles near coupling thresholds. The unstable 8Be nucleus is described as 2αBEC, and the C-12 Hoyle state (HS) as 3αBEC. Confirmation of the existence of more complex forms of αBEC could provide a basis for expanding scenarios for the synthesis of medium and heavy nuclei in nuclear astrophysics.
The consideration of αBEC as an invariant phenomenon indicates possibility of its search in the relativistic fragmentation. A practical alternative is provided by NTE layers longitudinally exposed to relativistic nuclei. The invariant mass of ensembles of He and H fragments can be determined from emission angles in the approximation of conservation of momentum per nucleon of a parent nucleus [2]. Owing to extremely small energies and widths, the Be-8 and HS decays, are identified in fragmentation of light nuclei by an upper constraint on the invariant mass. Having been tested, this approach has been used to identify Be-8 and HS and search for more complex states of αBEC in fragmentation of medium and heavy nuclei. Recently, based on the statistics of dozens of Be-8 decays, an enhancement in probability of detecting Be-8 in an event with an increase in number of relativistic alpha particles was found [3]. A preliminary conclusion is drawn that contributions of B-9 and HS decays also increase. The exotically large sizes and lifetimes of Be-8 and HS allowing suggesting possibility of synthesizing αBEC by successively connecting the emerging alpha particles. The main task of the forthcoming stage of the project is to clarify the relation between the appearance of Be-8 and HS and alpha multiplicities and search on this basis for decays of the 4αBEC [4]. In this regard, the BECQUEREL experiment aims to measure multiple channels of Kr-84 fragmentation below 1 GeV per nucleon in GSI (Darmtadt). There are a sufficient number of NTE layers, transverse scanning of which on the motorized microscope Olympus BX63 makes it possible to achieve required statistics. However, the low energy complicates the identification of HS and 4αBEC. NTE layers exposed to heavy nuclei at several GeV per nucleon will make it possible to apply well-established approaches to analysis. The acceleration of Xenon nuclei up to 3.8 GeV per nucleon and the extraction of their beam in the recent run of the NICA accelerator chain made it possible to take practical steps towards nuclear emission irradiation near the accelerator and in the area of the flagship BM@N experiment.

[1] P.I. Zarubin, Lect. Notes in Phys. 875, Clusters in Nuclei, Volume 3. Springer Int. Publ., 51 (2013); arXiv:1309.4881.
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[3] A.A. Zaitsev et al., Phys. Lett. B 820 (2021) 136460; arXiv: 2102.09541.
[4] D.A. Artemenkov et al., Phys. At. Nucl., 85, 528 (2022); arXiv: 2206.09690.

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