Topology of “ white ” stars in relativistic fragmentation of light nuclei

N. P. Andreeva[1), V. Bradnova[2), S. Vokal[2,4), A. Vokalova[2), A. Sh. Gaitinov[1), S. G. Gerasimov[3), L. A. Goncharova[3), V. A. Dronov[3), P. I. Zarubin[2)*, I. G. Zarubina[2), A. D. Kovalenko[2), A. Kravchakova[4), V. G. Larionova[3), O. V. Levitskaya[5), F. G. Lepekhin[5), A. I. Malakhov[2), A. A. Moiseeko[6), G. I. Orlova[3), N. G. Peresadko[3), N. G. Polukhina[3), P. A. Rukoyatkin[2), V. V. Rusakova[2), N. A. Salmanova[3), V. R. Sarkisyan[6), B. B. Simonov[5), E. Stan[2,7),R. Stanoeva[2,8), M. M. Chernyavsky[3), M. Haiduc[7), S. P. Kharlamov[3), I. Tsakov[8), T. V. Schedrina[2)

The BECQUEREL Collaboration[**]

[1)Institute of Physics and Technology, Almaty, Kazakstan..
[2)Joint Institute for Nuclear Research, Dubna, Russia.
[3)Lebedev Institute of Physics, Russian Academy of Sciences, Moscow, Russia
[4)University of P. J. Safaric, Kosice, Sloval Republik.
[5)Institute of Nuclear Physics, Russian Academy of Sciences, Gatchina, Russia.
[6)Institute of Physics, Erevan, Armenia
[7)Institute of Space Sciences, Bucharest-Maguerele, Romania.
[8)Institute of Nuclear Researches and Nuclear Energy, Bulgarian Academy of Sciences, Bulgaria.

[*]E-mail: zarubin@lhe.jinr.ru
[**]Web-site: becquerel.lhe.jinr.ru

In the present paper, experimental observations of the multifragmentation processes of light relativistic nuclei carried out by means of emulsions are reviewed . Events of the type of “white” stars in which the dissociation of relativistic nuclei is not accompanied by the production of mesons and the target-nucleus fragments are considered.

A distinctive feature of the charge topology in the dissociation of the Ne, Mg, Si, and S nuclei is an almost total suppression of the binary splitting of nuclei to fragments with charges higher than 2. The growth of the nuclear fragmentation degree is revealed in an increase in the multiplicity of singly and doubly charged fragments with decreasing charge of the non-excited part of the fragmenting nucleus.

The processes of dissociation of stable Li, Be, B, C, N, and O isotopes to charged fragments were used to study special features of the formation of systems consisting of the lightest alpha, d, and t nuclei. Clustering in form of the ^{3}He nucleus can be detected in “white” stars via the dissociation of neutron-deficient Be, B, C, and N isotopes.

INTRODUCTION

The charge topology of fragments in peripheral interactions of light nuclei of an initial energy above 1 GeV per nucleon may be considered as an effective characteristic of the nuclear multifragmentation phenomenon. In this energy range, a regime of limiting fragmentation of nuclei sets in, that is, the fragment spectrum is invariable with respect to the collision energy and the target-nucleus composition.

In the investigation of the multifragmentation at relativistic energies, the possibilities of observing the final states consisting of charged fragments and their spectroscopy are defined by the accuracy of angular measurements. Owing to the best spatial resolution (0.5 μm), the nuclear emulsion ensures the angular resolution of the tracks of relativistic fragments of about 10^{-5} rad. This enables one to observe completely all the possible decays of nuclear excited states to fragments. For example, over a track length of 1 mm, one can surely distinguish a process $^8Be \rightarrow 2\alpha$, which is revealed for a momentum of 4.5 GeV/c per nucleon as a pair of tracks within an angular cone of about $2\cdot 10^{-3}$ rad. Such narrow decays are rather frequently observed in the fragmentation of relativistic oxygen nuclei, as well as heavier ones.

The topologic characteristics of the events in the dissociation of light nuclei in peripheral interactions were investigated by the emulsion technique for the following nuclei ^{12}C [1-6], ^{22}Ne [7,12],

^{24}Mg [13], ^{28}Si [14-16], ^{16}O [17, 18], ^{6}Li [19-22], and ^{10}B [23-25] at energies of the order of a few GeV per nucleon .The dissociation of the ^{16}O and ^{32}S nuclei at an energy of 200 GeV per nucleon was studied in ref. [17, 26, 27]. All these results are notable for their exceptional completeness and reliability. They may turn out to be useful for planning investigations on nuclear multifragmentation with a high statistical provision.

The present paper gives the data on the dissociation channels for a wide range of light nuclei in events of the "white" star type. The experimental data on the relations between the nuclear dissociation channels being observed give an idea both of the general features of nuclear fragmentation processes and the special ones associated with the structure of individual nuclei. The results for the ^{24}Mg, ^{14}N, and ^{7}Be nuclei are presented for the first time. The results concerning other nuclei in question were obtained by using the events from earlier published data that were selected on the basis of more rigid criteria. Emulsions were exposed to beams of energy of a few Gev per nucleon at the JINR synchrophasotron and nuclotron, while to beams of energy of 200 GeV per nucleon - in CERN.

For the sake of illustration of the selection criteria, fig. 1 presents an event of the multifragmentation of a ^{28}Si nucleus of momentum 4.5 GeV/c per nucleon. Of particular interest is a group of projectile fragments with total charge Z = 13 within a narrow cone of angles of the order of a few degrees. The magnitude of the cone is defined by the ratio of the transverse Fermi momentum to the momentum per nucleon of the primary nucleus. The tracks of relativistic fragments remain in one emulsion layer sufficiently for reconstructing a continuous three-dimensional image of this group of tracks. The mass identification of relativistic H and He isotopes in emulsion is possible via the determination of the mean angle of track scattering and the total momentum connected with it.

The longitudinal momenta of fragments per nucleon are equal, within a few percent, to the momenta of the nucleons of the primary nucleus. The excitation energy of a system of fragments is defined by their multiplicity and the emission angles. It can be estimated as the difference between the invariant mass of the fragmenting system and the mass of the primary nucleus and amounts to a few MeV per nucleon of the fragment. The angular correlations of fragments reflect the angular momentum of the produced system. In fig.1, one can see, in a broader cone, tracks with minimal ionization from produced mesons. In addition, in the interaction peak, there are tracks from strongly ionizing target-nucleus fragments of energy of the order of several tens of MeV. Thus, the separation of the kinematic regions of the fragmentation of colliding nuclei is clearly revealed in the interaction.

Multifragmentaion in "white" stars. When accumulating data on nuclear multifragmentation, events without tracks from charged particles are selected between the areas of the fragmentation of a projectile and the target-nucleus. As a rule, in such events the primary nucleus charge is totally transferred into a narrow angular cone of fragmentation. The most obvious interpretation is provided for the events, which contain no tracks also from the target-nucleus fragments. They are produced in the case of a minimal energy transfer to the fragmenting nucleus. Events of such a type are called "white" stars because of their appearance. Their fraction constitutes few percent of the total number of inelastic events. Their name reflects not only the outward look of the event, but also a sharp decrease of ionization losses (in a limiting case, by a factor of Z) in the transition from the primary nucleus track to the narrow cone of secondary tracks. The formation of "white" stars is induced by the electromagnetic interactions of the target-nucleus with virtual photons and by the diffraction scattering on peripheral target neutrons.

In the search for events of this type, of important practical advantage is the requirement of charge conservation, which makes it possible to exclude in the beam admixtures from lighter nuclei with a close charge-to-mass ratio. This condition is essential when emulsion is exposed to the secondary beams of radioactive nuclei having a rather complicated composition. We note that the above-mentioned criteria of selection of "white" stars along with the requirement of conservation of the energy flux in the fragmentation cone can be used in a future experiment dealing with the study of global features of the fragmentation of heavy nuclei in peripheral dissociation processes.

Loosely bound cluster systems. The goal of our experiments is the study of the picture of the phase transition of nuclear matter from the state of a quantum liquid to that of a quantum gas consisting of a large number of nucleons and the lightest nuclei that occurs near the energy thresholds. The term "lightest nuclei" implies deuterons and tritons, as well as ^{3}He and ^{4}He nuclei, that is, stable systems having no excited states below nucleon decay thresholds.

The present-day interest in the study of such phase transitions is motivated by the prediction of the properties of such states as loosely bound cluster systems [28-30]. The spatial extension of these systems can essentially exceed the sizes of the fragments (Efimov 's states [28] near the threshold of the decay of 3 - body systems, light nuclei having the structure of a molecular type [29], the Bose condensate of dilute

α particle gas in Nα nuclei [30]). A multifragmentation process going with an adiabatic transfer of excitation and without nucleon exchange may be interpreted as a disappearance of the Coulomb barrier because of a simultaneous increase in distances between charged clusters.

The study of such states on the scale typical of the nucleon and cluster structure of the nucleus is of interest for nuclear astrophysics. For example, thanks to an essential decrease in the Coulomb repulsion in such extended systems, the latter can play the role of intermediate states in nucleosynthesis processes in stars. The topologies established can turn out to be useful for clearing up the variants of the nuclear synthesis as processes inverse to those of their fragmentation.

PARTICULAR FEATURES OF THE FRAGMENTATION OF Ne, Mg, Si, and S NUCLEI

Multifragmentation of ^{24}Mg nuclei. "White" stars were sought in the dissociation of the ^{24} Mg nuclei of a kinetic energy of 3.65 GeV per nucleon by viewing by means of microscopes along the primary nucleus track up to the interaction peaks (e.g., ref.[25]). 83 events of this type were found in which almost all secondary tracks were confined within a 4^{o} angular cone to the primary track direction . The value of the charge of a particle forming the track in emulsion was estimated by the density of ruptures on the track and the number of δ electrons. The distribution of the events with respect to the charge topology of fragments is given in table 1. The upper row is the charge of a fragment with Z > 2, the second row the number of singly-charged fragments, the third one - the number of doubly-charged fragments, and the bottom one the number of the events found with this topology. The observation of events with an 11 + 1 topology was effective with a level of about 50 % since the singly charged tracks were screened by the second track of a large ionization.

Table 1 contains the production channels for "white" stars starting with the separation of individual singly- and doubly -charged fragments from a "cold remainder" of the primary nucleus to its total breakup into lightest nuclei. In no one of these events there are more than one track from the relativistic fragments with Z > 2. The obvious particular feature is the absence of the events of binary and triple splitting of light nuclei to fragments heavier than the alpha particle, which suggests the dominance of the contribution from the multifragmentation process. Earlier, $Mg^{*}\rightarrow B+N$ splitting alone [31] without an additional emission of charged particles was discovered in an analysis of 1666 interactions. Thus, the multifragmentation processes are dominating, in spite of their higher thresholds. This fact is can be explained by a high density of multi-particle states.

It is planned to analyze the events due to a total Mg breakup using much more information with identification of lightest nuclei. In so doing, there will arise a possibility of reconstructing the invariant mass of a system being disintegrated and its subsystems (e.g., Nα ones). By the present time, two events that are due to the decay of a ^{24}Mg nucleus into six He nuclei are found. One of them is identified as $5^{4}He+^{3}He$, they do not enter the statistics of table 1 as far as these events are accompanied by single fragments of the target nucleus. Nevertheless, they give sufficient grounds to pursue further search for the 6 alpha configurations over large lengths of the primary tracks of ^{24}Mg nuclei.

Multifragmentation of ^{22}Ne nuclei. We compare the particular features of the ^{24}Mg nucleus fragmentation with a large amount of information on the interactions of neighboring nuclei. Table 2 shows the charge topology distribution for 103 "white" stars originating from ^{22}Ne nuclei with the energy 3.27 GeV per nucleon that were selected from 4100 inelastic events [7]. In this case as well, there are no binary splitting events. In ref. [31], using some other statistic set from 4155 events, binary ^{22}Ne splittings were also not observed.

A noticeably more evident role of the helium isotopes in the ^{22}Ne fragmentation may be associated with the fact that, contrary to the symmetric Mg nucleus, the ^{22}Ne nucleus has a pair of additional external neutrons. This situation can be employed for more effective generation and detection of systems consisting of a large number of α particles in initiating dissociation via a knockout of external neutrons. We found three events from the decay of ^{22}Ne nuclei to five He nuclei (table 2) the tracks of which were confined within a cone of 3^{o}. Of them, in two events, all the tracks were even within 1^{o}. These discoveries confirm once more unique capabilities of nuclear emulsions as applied to the investigation of multiparticle systems consisting of the lightest nuclei with minimal relative four-velocities (or relative Lorentz factors).

Multifragmentation ^{28}Si and ^{32}S nuclei. A statistic set of 116 "white" stars from the ^{28}Si nuclei of the energy of 3.65 GeV per nucleon demonstrates the same particular feature, that is, the transition to the multifragmentation (table 3) occurs by avoiding a binary splitting [14]. In ref. [31], using another sample from 1900 inelastic interactions, one observed an event $Si^{*}\rightarrow O+C$ alone. It is interesting to note that the transition to a total break up of a ^{28} Si nucleus proceeds with an increasing contribution to the final states from the H isotopes with respect to the He isotopes. It has to be decided whether this fact is a consequence of a weakening of the alpha clustering in nuclei with increasing A. The results mentioned represent an event sample from earlier obtained data [7, 14]. At the same time, these papers contain rich information, which is useful for planning experiments with varying inelasticity of selected collisions.

We also give the results obtained from an exposure involving ^{32}S nuclei of the energy of 200 GeV per nucleon. In this case, the angular fragmentation cone is 0.5 ^{o}. In table 4 the H isotope separation channel is seen to be dominant. In spite of poor statistics, a multifragmentation is revealed in the topology of 193 "white" stars.

It is of interest to explore the "white" star topology for heavy nuclei. Single events from a total breakup of Pb nuclei were observed in an emulsion exposed to ultra-relativistic Pb nuclei of the energy of 160 GeV, at CERN. However it is impossible to perform a detailed study within the cone of the fragmentation of heavy nuclei even by the emulsion technique. It appears that this investigation can be carried out with the use of intense relativistic beams of heavy nuclei by measuring the total ionization and the energy fluxes in a total solid angle.

PARTICULAR FEATURES OF FRAGMENTATION OF B, C, N, AND O NUCLEI

Multifragmentation of ^{12}C и ^{16}O nuclei. The probabilities of formation of the systems consisting of a small number of fragments with Z = 1 and 2 and their properties can be explored by means of a selection of "white" stars originating from the fragmentation of B, C, N, and O isotopes. Detailed information on the multifragmentation of the nuclei belonging to this group may be assumed as a basis for understanding processes occurring in heavier nuclei. The dissociation of B and C nuclei to three-body systems can proceed via the separation of the lightest nuclei , that is, alpha particles, deuterons, tritons, and ^{3}He nuclei, from the core in the form of an unstable ^{8}Be nucleus , as well as via a direct fragmentation of them to and He isotopes.

The "white" stars from the$^{12}C^{*}\rightarrow 3\alpha$ channel at the energy of 3.65 GeV per nucleon were studied in refs. [4-6]. In particular, one demonstrated the role of the channel with a ^{8}Be nucleus and one came to a conclusion about the transition to a direct multfragmentation with increasing total energy of a system consisting of three α particles. In ref. [31], using the statistics 2757 inelastic interactions, it was established that no one event of binary splitting had been observed through the only possible $^{12}C^{*}\rightarrow {}^{6}Li+{}^{6}Li$ channel.

In ref. 18, the "white" stars from the $^{16}O^{*}\rightarrow 4\alpha$ channel were investigated using a large amount of information (641 events). An analysis of the angular correlations gave evidence that the angular momentum was transferred to the systems of fragments and that the cascade decays via ^{8}Be and ^{12}C nuclei were nonessential. Tables 5 and 6 give the results of the selection of "white" stars using a sample of 2159 interactions of ^{16}O nuclei at the energy of 3.65 (72 stars) and at the energy of 200 (86 stars) GeV per nucleon.

Multifragmentation of ^{10}B nucleus. The study of the contribution from deuterons to the decays of odd-odd ^{6}Li [19-22], ^{10}B [23-25], and ^{14}N nuclei pursues the investigation of the multifragmentation of light even-even nuclei with dissociation only to α particles. The role of the deuteron as a cluster is especially pronounced in the "white" stars of ^{6}Li nuclei at the energy of 3.65 GeV per nucleon (in ref. [21] $^{6}Li^{*}\rightarrow d\alpha$ -74%, $^{6}Li^{*}\rightarrow {}^{3}He t^{*}$ – 13%, $^{6}Li^{*}\rightarrow tdp$ –13%).

The topology of "white" stars was investigated for ^{10}B nuclei at the energy of 1.0 GeV per nucleon. Table 7 presents the charge topology distribution of 41 "white" stars with the angular cone for secondary tracks to 15 ^{o}. The fraction of the $^{10}B^{*}\rightarrow d\alpha\alpha$ decays is 40 % of the events with a charge topology 2+2+1. The contribution of the $^{10}B^{*}\rightarrow d\,{}^{8}Be^{(*)}\rightarrow d\alpha\alpha$ channel is estimated to be 18±3 %. The decay of an unstable ^{9}B nucleus is not a basic source of the events with such a topology. This is suggested by the fact that the probability of observing a 4 + 1 topology in the $^{10}B^{*}\rightarrow p\,{}^{9}Be$ decay is small, as well as the contribution of ^{8}Be to $^{10}B\rightarrow p\,{}^{8}Be$ is also not large. It may be concluded that the direct three-body decays with "white" stars 2 + 2 + 1 configuration play a crucial role. Thus the decay topology $^{10}B^{*}\rightarrow d\alpha\alpha$ is indicative of an analogy with the $^{12}C^{*}\rightarrow 3\alpha$ decay.

In order to gain extended knowledge about the relation between the direct three-body decay and the decays via ^{8}Be nucleus, emulsion was exposed to relativistic ^{9}Be nuclei. A beam of ^{9}Be nuclei with momentum of 2 GeV /c per nucleon was formed in ^{10}B fragmentation after acceleration at the JINR nuclotron. The process of production of "white" stars with 2 α particles is initiated in the fragmentation with a breakup of one neutron. An analysis of the data will allow one to have an idea about clustering in the ^{9}Be nucleus and the probability of formation of ^{8}Be nucleus. This is expected to affect the yield of α particle pairs through n-^{8}Be and α-n-α excitations.

Multifragmentation of ^{14}N nucleus. It is interesting to find out the role of the three-body decays which has been defined for $^{10}B^{*}\to d\alpha\alpha$, $^{12}C^{*}\to 3\alpha$, and $^{16}O^{*}\to 4\alpha$, as well as to develop ideas of clustering in nuclei involving deuterons. To this end, emulsion was exposed to ^{14}N nuclei of the energy of 2.1 GeV per nucleon. The major goal is the study of the $^{14}N^{*}\to d\alpha\alpha\alpha$ "white" stars within the forward cone to 8 º. By the present time, data extracted from 540 interactions of N nuclei with the emulsion nuclei, including 25 "white" stars, were accumulated. Their distribution with respect to the charge topology is given in table 8. There is an evidence for an important role of the 2+2+2+1 charge configuration, which is related to ^{14}N decay. The noticeable role of the 6+1 configuration is seen to have analogy to the events with a Z = 1 fragment splitting in the dissociation of heavier symmetric nuclei.

Clustering that involves tritons. The study of the "white" stars of light odd-even stable nuclei (^{7}Li, ^{11}B, ^{15}N, and ^{19}F) can provide a basis for including tritons into the general picture. It is established that in the "white" stars originating from relativistic ^{7}Li nuclei, the $^{7}Li^{*}\to\alpha t$ channel constitutes 50 %, $^{7}Li^{*}\to\alpha dp$ - 30 %, and $^{7}Li^{*}\to\alpha pnn$ - 20 % [25]. As a next step, an exposure has been performed and the dissociation of ^{11}B nuclei of an the energy of 1.2 GeV is being analyzed. The major task of the experiment is the study of the "white" stars of the $^{11}B^{*}\to t\alpha\alpha$ channel.

PROSPECTS OF THE STUDY OF NEUTRON-DEFICIENT Be, B, C, and N ISOTOPES

Search for a "3He process" in ^{11}C, ^{10}C and ^{9}C decays. The ^{11}B nucleus is a daughter one in the β decay of a mirror ^{11}C nucleus. Therefore following the study of the "white" stars of the $^{11}B^{*}\to t\alpha\alpha$ and $^{11}B^{*}\to {}^{7}Li\alpha$ channels it is interesting to explore the ^{3}He role in ^{11}C decays. The decays via the $^{11}C^{*}\to {}^{3}He\alpha\alpha$ and $^{11}C^{*}\to {}^{7}Be\alpha$ channels may be analogous to those via the $^{12}C^{*}\to 3\alpha$ and $^{12}C^{*}\to({}^{8}Be)\alpha$ channels. Clustering in $^{12}C^{*}\to 3\alpha$ decays reflects the well-known "3α process" in stars. Observation of the cluster $^{11}C^{*}\to {}^{3}He\alpha\alpha$ decays would serve as a basis for studying the possible role of the "3He" process in nucleosynthesis in stars occurring by means of $^{11}C^{*}\to {}^{3}He\ \alpha\alpha$ fusion, that is, in helium media with a mixed composition of helium isotopes.

The ^{10}C nucleus is produced out of a ^{9}C nucleus by adding one neutron. However it appears that the addition of a neutron does not result in the formation in the ground state of ^{10}C clusters in the form of deuterons or ^{3}He nuclei. It is unlikely that the two-cluster structures will be produced in the form of ^{7}Be and ^{3}He nuclei, or in the form of a ^{8}B and a deuteron because of a high binding energy of such clusters in the ^{10}C nucleus. In the case of one external proton, an unstable ^{9}B can serve as the central part of the nucleus. In the structure with two external protons, the central part is represented by another but also unstable ^{8}Be nucleus. Such structures must apparently be similar to the Boromean structures of neutron-excess nuclei. In the present case, one or two external protons keep the ^{10}C nucleus from being decayed to nuclear resonant states.

It is of interest to get experimental information about the channels $^{10}C^{*}\to {}^{3}He^{3}He\alpha$ and $^{10}C^{*}\to {}^{7}Be\ {}^{3}He$ which permits one to make a generalization of the "3He process". In the above-mentioned irradiation of emulsion by the ^{10}B nuclei, we have already observed two "white" stars from a dissociation without target-nucleus excitation that are interpreted as $^{10}B^{*}\to \alpha t^{3}He \to ({}^{10}C^{*})\pi^{-}\to \alpha^{3}He^{3}He\pi^{-}$. They give an indication of the fact that there exists a ^{10}C three-cluster excitation mode. As an example, we note that the study of the $t\to {}^{3}He$ charge exchange process on emulsion nuclei has shown a high reliability of its observation [22]. The ^{10}C nucleus breakup can proceed in a cascade manner with the production in the intermediate state of ^{9}B, ^{8}Be and ^{6}Be unstable nuclei with few charged fragments produced in the final state. Thus, it is possible to study the decays of these nuclei.

It is suggested to form at the JINR nuclotron ^{11}C and ^{10}C beams and expose to them emulsions. For the beam generation, one preferred the $^{11}B\to {}^{11}C$ and $^{10}B\to {}^{10}C$ charge exchange processes to the fragmentation of heavier nuclei , so as to suppress the contribution from nuclei having close ionization.

Of all the nuclei being considered, the ^{9}C nucleus has the largest ratio of the number of protons to that of neutrons. This nucleus has an additional proton with respect to the ^{8}B nucleus. The binding energy of this proton is much higher than that of the external proton in ^{8}B. Perhaps, this is an effect of the interaction of two protons, which is analogous to the interaction of external neutrons in ^{6}He. Of special interest and urgency is the investigation of the probability of $^{9}C^{*}\to 3{}^{3}He$ decays with respect to $^{9}C^{*}\to p^{8}B$, $pp^{7}Be$, and to some other decay channels. It should be noted that the larger the ratio Z/N in the nucleus being investigated thanks to more complete probability of observing nucleons from the fragmenting nucleus, the wider the manifestation of the advantages of the emulsion technique in the study of the "white" stars.

The fusion $^{3}He^{3}He^{3}He \to {}^{6}Be^{3}He \to {}^{9}C$ is one more option of the "3He process". It's the β decay to a mirror ^{9}B nucleus that is not a bound one, results in the $^{9}B \to p\alpha\alpha$ decay. Thus, in a star medium, initially involving only the ^{3}He, can proceed a workout of ^{4}He. The 9C produced can take part in a further $^{4}He^{9}C \to {}^{13}N(\beta^{+}) \to {}^{13}C$ fusion under definite astrophysical conditions.

In the $^{9}C \to {}^{8}C$ fragmentation, a crossing of the boundary of proton stability takes place. In this case, there arises a possibility in studying nuclear resonances by means of multiple $^{8}C \to pp^{3}He^{3}He$ and $^{8}C \to pp^{3}He^{3}He$ decay channels, which possess a striking signature. It is quite possible that the study of these resonances would promote further development of the physics of loosely bound nuclear systems.

^{12}C nuclei with momentum 2.0 GeV/c per nucleon and intensity of about 10^{9}nuclei per cycle were accelerated at the JINR nuclotron and a beam of secondary nuclei with a magnetic rigidity corresponding to the ratio Z/A=6/9 was formed. The information obtained was used to analyze ^{9}C nucleus interactions in emulsion.

Clusterung in ^{8}B nucleus decays. The particular feature of the ^{8}B nucleus is a record low binding energy of one of the protons. Therefore, the ^{8} B nucleus is most likely to have the core in the form of a ^{7}Be nucleus and a loosely bound proton the spatial distribution of which mostly determines the value of the ^{8}B nucleus radius.

The special features of the structure of light neutron-deficient nuclei may underlie the so-called *rp*-processes. For example, the presence of a state of the proton-halo type [32] can positively affect the velocity of synthesis of light radioactive nuclei along the boundary of proton stability that decay to stable isotopes. In particular, ^{8}B halo reduces the Coulomb repulsion when $p^{3}He\alpha$ nuclei undergo a fusion in mixtures of the stable H and He isotopes in astrophysical systems. The ^{8}B nucleus being produced can either "wait for" the β decay or, in definite astrophysical scenarios, take part in fusion reactions $\alpha^{8}B \to {}^{12}N(\beta^{+}) \to {}^{12}C$. As compared with the ^{12}C synthesis via the ^{8}Be nucleus, this process features much longer life-time of the ^{8}B nucleus.

The ^{10}B nuclei with a momentum of 2.0 GeV/c per nucleon and an intensity of about 10^{8} nuclei per cycle were accelerated at the JINR nuclotron and a beam of secondary nuclei of a magnetic rigidity corresponding to Z/A = 5/8 ($^{10}B \to {}^{8}B$ fragmentation, as suggested in ref.[25]) was formed. Information on the ^{8}B interactions in emulsion had been obtained. We plan to determine the probabilities of forming "white" stars in $^{8}B \to {}^{7}Bep$, $\alpha^{3}Hep$, $^{6}Lipp$, and αdpp. In the $^{8}B \to {}^{7}B$ fragmentation, a crossing of the limits of proton stability also takes place. Thus, there arises a possibility of studying the decay channels $^{7}B \to p^{3}He^{3}He$ (an analog to ^{9}B) and $ppp^{4}He$. In order to investigate the ^{12}N structure and clear up the role played by ^{8}B in this nucleus it is intended to expose emulsion to the ^{12}N beam produced in the charge-exchange reaction $^{12}C \to {}^{12}N$. It is also possible to use the $^{12}N \to {}^{11}N$ fragmentation to study decays of one more nucleus being away from the valley of proton stability.

Clusterung in ^{7}Be nucleus decays The study of the ^{7}Be nucleus fragmentation is of interest as far as this nucleus may be a core in the ^{8}B nucleus. Using one and the same approach, it will be possible to compare the cluster structure of this nucleus with the ^{6}Li [21] and ^{7}Li [25] nuclei through the probabilities of forming "white" stars in the $\alpha^{3}H$ and $p^{6}Li$ channels.

Emulsion was exposed to ^{7}Be nuclei of the energy of 1.23 GeV per nucleon, the beam of which was formed at the JINR nuclotron on the basis of the charge-exchange reaction$^{7}LI \to {}^{7}Be$. As a result of viewing over all the primary tracks, 75 "white" stars with the total secondary track charge equal to 4 were found in a cone up to 15 ^{o}.The examples of such stars for 2+2 topologies with and without target excitation, as well as for 3+1 and 1+1+1+1 topologies are given in fig.2.

Table 9 shows the distribution of these stars over the charge topology channels. A channel with single-charged fragment splitting, which is unambiguously interpreted as $p^{6}Li$, is observed. As a particular feature, it is possible to note two cases of a total breakup of the nucleus to singly charged fragments. In the case of 36 events with 2+1+1 topology, 20 tracks with Z= 2 were identified as ^{3}He and 16 tracks - as ^{4}He using the method of determination of the total momentum by means of multiple scattering. To separate the He nuclei according to their mass, use was made of a limiting value of the total momentum of Pβ=5.1 GeV/c per nucleon fragments. To pursue further investigation it is of interest to analyze the $^{7}Be \to {}^{6}Be(n) \to pp^{4}He$ (n) channel, which is accompanied by the target-nucleus fragmentation initiated by a neutron.

In fig.3, the two-body decays are presented by points the coordinates of which are the total momenta Pβ of fragments with Z = 2. The maximum Pβ value is attributed to the ordinate, and the minimum one to the abscissa. The distribution asymmetry is clearly seen. The $^7Be^* \to \alpha ^3He$ decay, that occurs for a minimal excitation above the decay threshold, as compared with other channels, is dominant in 22 events with 2+2 topology. In the latter, 5 events are identified as the $^7Be^* \to (n)\ ^3He^3He$ decay. Thus, a clustering with ^3He formation is clearly demonstrated in the "white" stars of the ^7Be nucleus which makes it possible to put the question as to whether this clustering is revealed in neighboring neutron-deficient nuclei.

CONCLUSIONS

The experimental observations of the multifragmentation of light relativistic nuclei carried out by means of emulsions have been reviewed. Events of the "white" star type, which contain only tracks of the relativistic nucleus fragments, are selected. They involve neither charged meson tracks nor target-nucleus ones. The multifragmentation topology has been considered for these events.

The characteristic feature of the charge topology in the fragmentation of Ne, Mg, Si and S nuclei implies an almost total suppression of pairing splitting of nuclei to fragments with charges larger than 2. Processes with separation of individual fragments occurring at minimal excitation energies are predominant. The growth of the nucleus fragmentation degree is revealed in an increase of the multiplicity of Z= 1,2 fragments with decreasing charge of the non-excited part of the fragmenting nucleus.

In multifragmentation processes of stable Li, Be, B, C, N. and O isotopes special features of the formation of systems involving the lightest α, d and t nuclei have been determined. In addition to the alpha clustering, a clustering of nucleons in the form of deuterons in ^6Li and ^{10}B decays, as well as of tritons in ^7Li decays has been revealed. Besides, the multiparticle dissociation is found to be important for these nuclei. Emulsions exposed to relativistic ^{14}N and ^{11}B isotopes are being analyzed with the aim to study clustering of these types.

The emergence of the ^3He clustering can be detected in "white" stars, which is due to the neutron-deficient Be, B, C and N dissociation. Irradiation of emulsions by ^7Be, ^8B, and ^9C nuclei has been performed. Irradiation by ^{10}C, ^{11}C, and ^{12}N are planned. An analysis of the "white" stars from ^7Be nuclei demonstrates the ^3He clustering.

Emulsions provide a unique basis for reconstructing relativistic multiparticle systems. Some of these systems are expected to play the role of the initial or intermediate loosely bound states in a fusion of more than two nuclei in nucleosynthesis in stars. The observation basis described in the paper can be employed in the search for such states.

In conclusion, we would like to remember the names of our leaders in the domain of investigations with relativistic nuclei. Unfortunately, they are no more among the living. The foundations of the research along these lines had been laid by Academician A.M.Baldin. For many years, M.I.Adamovich, V.I.Ostroumov, Z.I.Solovieva, K.D.Tolstov, M.I.Tretiakova, and G.M.Chernov had been leaders of the investigations carried out by nuclear emulsion technique at the JINR synchrophasotron.

The results presented are based on a laborious visual search and measurements to which our laboratory assistants A.V. Pissetskaia (FIAN), L.N.Tkach (PINPh), N.A.Kachalova, I.I.Sosulnikova, A.M.Sosulnikova, and G.V. Stelmach (JINR) have made a valuable contribution. I. I. Marjin (JINR) has ensured the maintenance of our microscopes. Emulsions have been processed with high quality by the chemical team of the Laboratory of High Energies of JINR. A valuable contribution to our work has been given by the specialists of the Veksler and Baldin Laboratory of JINR ensured the nuclotron operation. We are grateful to the leaders of the Flerov Laboratory of Nuclear Reactions of JINR who has rendered support in urgent acquisition of emulsions.

This work was supported by the Russian Foundation for Basic Research (project nos.96-1596423,
02-02-164-12a, 03-02-16134, 03-02-17079 and 04-02-16593), VEGA 1/9036/02 Grant from the Agency for Science of the Ministry for Education of the Slovak Republic and the Slovak Academy of Sciences, and grants from the JINR Plenipotentiaries of the Slovak Republic, the Czech Republic and Romania in 2002 and 2003.

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TABLES

Table 1. The distribution of "white" stars with respect to the charge topology in dissociation of ^{24}Mg of the energy of 3.65 GeV per nucleon.

Z_f	11	10	10	9	9	8	8	8	7	7
$N_{Z=1}$	1	2	-	3	1	4	2	-	3	1
$N_{Z=2}$	-	-	1	-	1	-	1	2	1	2
N_{ev}	10	14	8	5	9	1	7	4	4	2
Z_f	6	5	5	5	4	4	3	-	-	-
$N_{Z=1}$	2	5	3	1	6	4	5	6	4	2
$N_{Z=2}$	2	1	2	3	1	2	2	3	4	5
N_{ev}	4	2	1	1	2	1	3	1	2	2

Table 2. The distribution of "white" stars with respect to the charge topology in dissociation of ^{22}Ne of the energy of 3.27 GeV per nucleon.

Z_f	9	8	8	7	6	6	5	5	5+3	4	4+3	-	-
$N_{Z=1}$	1	-	2	1	-	2	1	3	-	-	3	2	-
$N_{Z=2}$	-	1	-	1	2	1	2	1	1	3	-	4	5
N_{ev}	22	51	6	7	5	2	1	1	1	2	1	1	3

Table 3. The distribution of "white" stars with respect to the charge topology in dissociation of ^{28}Si of the energy of 3.65 GeV per nucleon.

Z_f	13	12	12	11	11	10	10	10	9	9	9	8	8	8	7	7	7
$N_{Z=1}$	1	-	2	1	3	-	2	4	1	3	5	6	2	4	3	5	7
$N_{Z=2}$	-	1	-	1	-	2	1	-	2	1	-	-	2	1	2	1	-
N_{ev}	9	3	15	11	6	2	7	2	2	8	3	2	5	6	1	3	3

Z_f	6	6	6	6	5	5	4	-	-	-
$N_{Z=1}$	2	4	6	8	3	5	2	2	8	10
$N_{Z=2}$	3	2	1	-	3	2	4	6	3	2
N_{ev}	3	5	8	1	1	3	1	1	2	3

Table 4. The distribution of “white” stars with respect to the charge topology in dissociation of ^{32}S of the energy of 200 GeV per nucleon.

Z_f	15	14	14	13	13	12	12	11	11	10	10	10	9	8	8	7+3	7	5+3
$N_{Z=1}$	1	-	2	1	3	2	4	3	5	2	4	6	3	-	6	4	3	4
$N_{Z=2}$	-	1	-	1	-	1	-	1	-	2	1	-	2	4	1	1	3	2
N_{ev}	99	11	48	7	6	3	4	4	1	1	2	1	1	1	1	1	1	1

Table 5. The distribution of “white” stars with respect to the charge topology in dissociation of ^{16}O of the energy of 3.65 GeV per nucleon.

Z_f	7	6	6	5	5	4	4	-	-
$N_{Z=1}$	1	2	-	3	1	-	2	-	2
$N_{Z=2}$	-	-	1	-	1	2	1	4	3
N_{ev}	18	7	21	2	10	1	1	9	3

Table 6. The distribution of “white” stars with respect to the charge topology in dissociation of ^{16}O of the energy of 200 GeV per nucleon.

Z_f	7	6	6	5	5	4	3	3	-	-	-
$N_{Z=1}$	1	-	2	1	3	2	1	3	-	2	4
$N_{Z=2}$	-	1	-	1	-	1	2	1	4	3	2
N_{ev}	49	6	10	5	1	3	2	2	2	4	2

Table 7. The distribution of “white” stars with respect to the charge topology in dissociation of ^{10}B of the energy of 1 GeV per nucleon.

Z_f	4	3	-	-
$N_{Z=1}$	1	-	3	1
$N_{Z=2}$	-	1	1	2
N_{ev}	1	5	5	30

Table 8. The distribution of “white” stars with respect to the charge topology in dissociation of ^{14}N of the energy of 2.1 GeV per nucleon.

Z_f	6	5	4	3	-	-
$N_{Z=1}$	1	2	1	4	3	1
$N_{Z=2}$	-	-	1	-	2	3
N_{ev}	6	3	1	1	2	12

Table 9. The distribution of “white” stars with respect to the charge topology in dissociation of ^{7}Be of the energy of 1.2 GeV per nucleon.

Z_f	3	-	-	-
$N_{Z=1}$	1	4	2	-
$N_{Z=2}$	-	-	1	2
N_{ev}	7	2	38	28

FIGURES

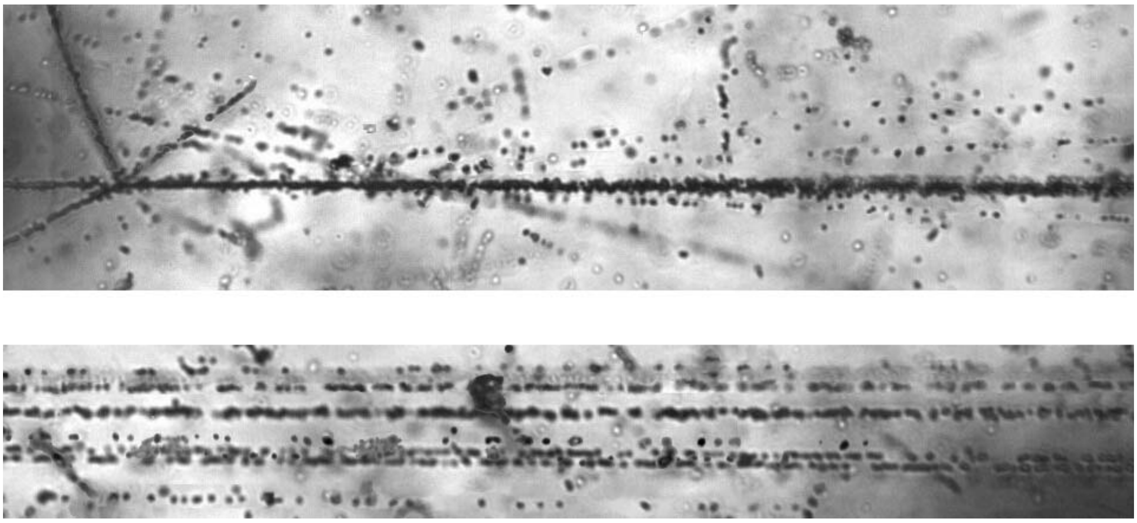

Fig. 1 Event of the fragmentation of a ^{28}Si nucleus of the energy of 3.65 GeV per nucleon in a peripheral interaction on an emulsion nucleus. On the upper photograph one can see the interaction peak and the jet of fragments in a narrow angular cone along with four accompanying single-charged particles in a wide cone and three fragments of the target-nucleus. Moving toward the fragment jet direction (upper photograph) it is possible to distinguish 3 fragments of hydrogen and 5 fragments of helium. An intensive track on the upper photograph (the third one from above) is identified as a very narrow pair of Z=2 fragments corresponding to the ^{8}Be decay. A three-dimensional image of the event was reconstructed as a plane projection by means of an automated microscope (Lebedev Institute of Physics, Moscow) of the PAVIKOM complex.

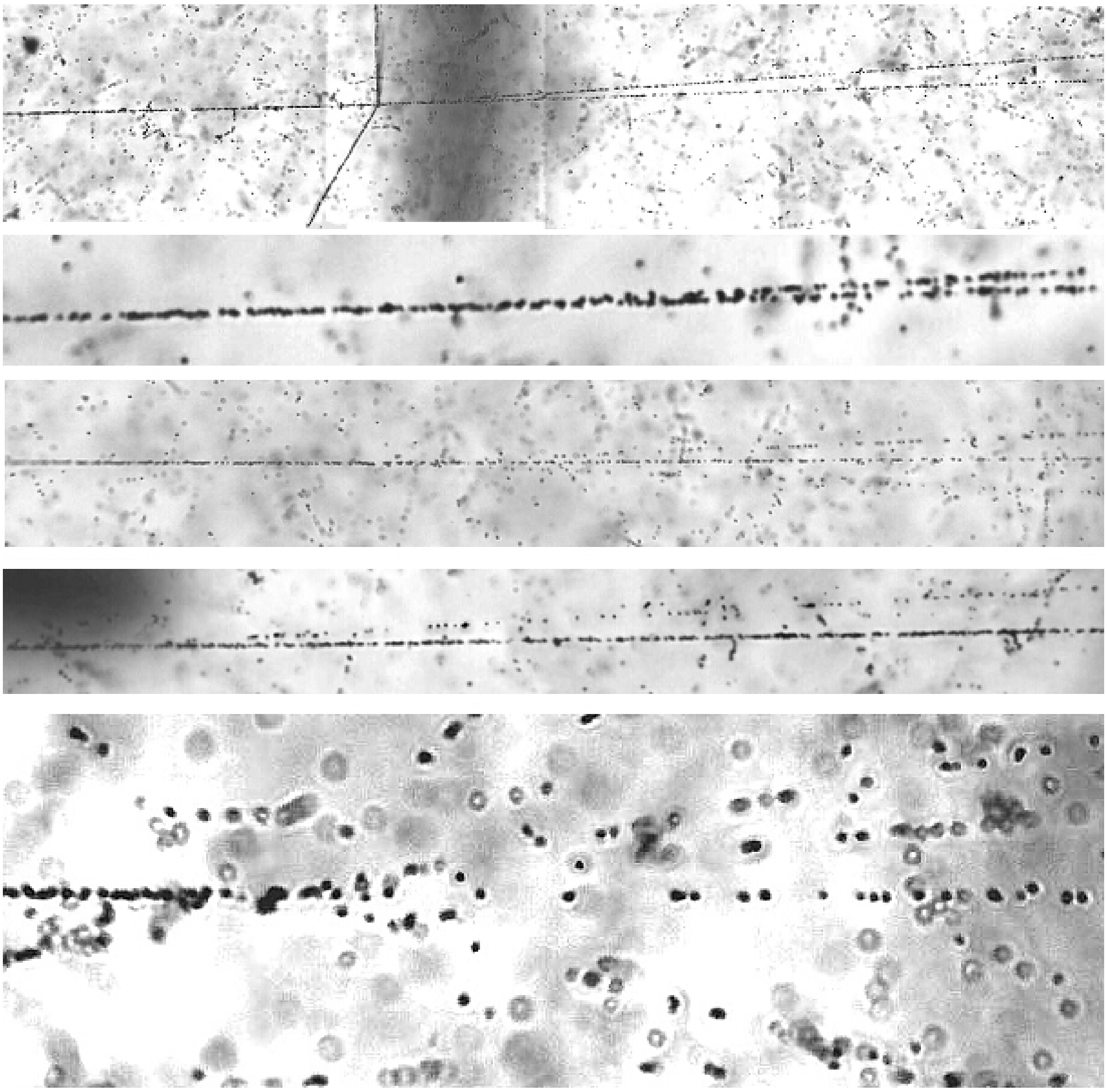

Fig.2 Examples of the events from the peripheral ^{7}Be dissociation in emulsion. The upper photograph is a splitting to two He fragments with production of two target-nucleus fragments. Below there are “white” stars with splitting to two He, one He and two H, one Li and one H and four H fragments.

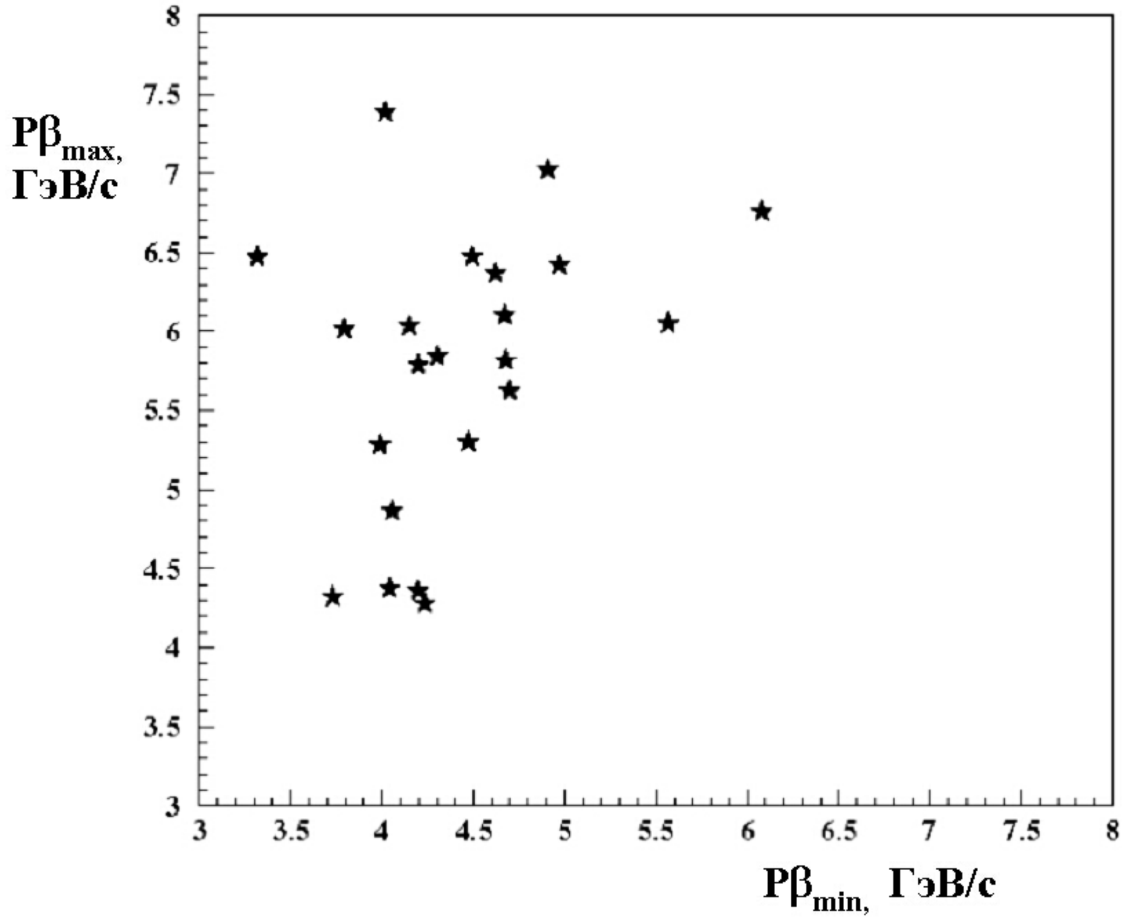

Fig. 3. The distribution of the “white” stars from a ^{7}Be nucleus of the energy of 1.23 GeV per nucleon with a decay to two He fragments with respect to minimum and maximum momenta.