A HIC Primitive Spinodal Decomposition Signature

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May, 20^{th}, 2004

Abstract

Evidence of a primitive spinodal decomposition has been obtained for central Ni+Ni Heavy Ion Collision, since higher order charge correlations show a peak when four fragments of size equal to 6 are produced with an excitation of 4.75 MeV. This can be considered as a signature of a primitive breakup in equal sized fragments with a privileged fragment size. This computational result confirms other experimental and theoretical evidences about spinodal decompostion in HIC.

1 Introduction

Heavy Ion Collisions are expected to experience a liquid-gas phase transition due to the specifics of the internucleonic interaction, which is attractive in both the long and intermediate ranges and repulsive in the short range. It is possible that a wide zone of phase space is explored when two nuclei collide, including a region where liquid and gas phases coexist, namely the spinodal region. At this spinodal region, incompressibility is negative and uniform nuclear matter is unstable, leading to multifragmentation due to the increase of density fluctuations [1] [2]. Dynamical simulations based on Boltzmann equation, such as Landau-Vlasov (LV), Boltzmann-Uehling-Uhlenbeck (BUU) or Boltzmann-Nordheim-Vlasov (BNV), describe the time evolution of the density of a one-body system, ignoring those correlations whose order is larger than the order of binary correlations, neglecting fluctuations around the mean trajectory of the system, which altogether comes out to be quite inconvenient to study the spinodal instability zone [1]. As shown by Guarnera et. al. [3], a spinodal decomposition produces a "primitive breakup" where equal sized fragments have a privileged fragment size, which is related to the wave lenghts of the most unstables modes of nuclear matter. Tabacaru et. al. have obtained reduced velocity correlations between fragments and did not find a bubble-like profile, which excludes surface instabilities that might cause

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multifragmentation. They also computed higher order charge correlations, defined as the ratio between the number of correlated fragments and the number of uncorrelated fragments, obtaining evidence of a privileged production of equal sized fragments [4]. Chomaz et. al. have introduced a scenario inspired on experimental data, where a gently compressed systems expands and reaches thermal equilibrium approximately at the time when the system enters into the spinodal region. At this moment, density fluctuations break up the system into several hot fragments and particles. When fragments are released from the nuclear force, configuration frozens and fragments only interact with each other via coulomb force. At this moment, system has explored so much phase space that it can be described by statistical models and there is no contradiction between statistical or dynamical approximations. Statistical approximations describe the time evolution of the system and the phase diagram. Meanwhile, dynamical approximations start up in phase diagram and are more related to the thermodynamics of non extensive systems. Barrañón et. al. have obtained computational evidence about the inverse relation between entropy and the residual size, using LATINO dynamical model to study the spinodal decomposition region of central Ni+Ni HIC at intermediate energies [5] . In this very study, evidence is obtained about a primitive spinodal decomposition for Ni+Ni central HIC at intermediate energies.

2 Methodology.

Heavy Ion Collisions were simulated using LATINO semiclassical model where binary interaction [6] is reproduced with a Pandharipande potential built up of Yukawa potentials linear combinations, whose coefficients are designed to both reproduce nuclear matter ground state properties and to fulfill Pauli exclusion principle [7]:

$$V_{nn} = V_{pp} = V_0\Big(\frac{e^{-\mu_0 r}}{r} - \frac{e^{-\mu_0 r_C}}{r_c}\Big) \tag{1}$$

and:

$$V_{np} = V_r\Big(\frac{e^{-\mu_r r}}{r} - \frac{e^{-\mu_r r_C}}{r_c}\Big) - V_a\Big(\frac{e^{-\mu_a r}}{r} - \frac{e^{-\mu_a r_a}}{r_a}\Big) \tag{2}$$

Clusters are identified with an Early Cluster Recognition Algorithm that optimizes configurations in energy space. A most bound partition is obtained minimizing the sum of energies of the clusters belonging to each partition:

$$\{C_i\} = argmin\Big[E_{\{C_i\}} = \sum_i E_{int}^{C_i}\Big] \tag{3}$$

where the energy of each cluser is given by :

$$E_{int}^{C_i} = \sum_i \Big[\sum_{ij \in C_i} K_j^{CM} + \sum_{j,k \in C_i, j \le k} V_{jk}\Big] \tag{4}$$

where the first sum includes the partition clusters, K_j^{CM} is the kinetic energy of the particle j measured in the center of mass of the cluster containing particle j, and V_{ij} is the internucleonic potential. The algorithm uses "simmulated annealing" to find the most bound partition and optimizes the partition in energy space.

Projectile energy is in the range of 600 to 2000 MeV and system evolves until its microscopic composition is rather frozen though some monomers are ejected. This time can be identified using the Persistence Microscopic Coefficient, defined as the probability that two particles belonging to the partition X remain bound in partition Y:

$$P\Big[X,Y\Big] = \frac{1}{\sum_{cluster} n_i} \sum_{cluster} \frac{n_i a_i}{b_i} \qquad (5)$$

where b_i is equal to the number of pairs of particles belonging to the cluster C_i of partition X while a_i is equal to the number of particle pairs belonging to cluster C_i of partition X that also belong to a given cluster C'_i of partition Y. n_i is the number of particles in cluster C_i.

Higher order charge correlations were introduced by Moretto et. al. [8] and are given by:

$$\left.\frac{Y\Big(\Delta Z, < Z >\Big)}{Y'\Big(\Delta Z, < Z >\Big)}\right|_M \qquad (6)$$

where $Y\Big(\Delta Z, < Z >\Big)$ is equal to the number of fragments produced for given values of ΔZ and $< Z >$.

3 Results

Higher order charge correlations were obtained for central HIC Ni+Ni. These higher order correlations show a peak for a fragment size equal to 6, with four equal sized fragments produced with this privileged size and an excitation equal to 4.75 MeV. This can be considered a primitive breakup signature in equal sized fragments of a privileged size. Hence, this dynamical study supports other experimental and theoretical evidences of spinodal decomposition in HIC, such as the experimental study reported by Borderie et. al. [9] where a fosil spinodal decomposition signature for HIC collision $^{129}Xe +^{nat} Sn$ at 32 AMeV was obtained. At that very experiment, liquid-gas coexistence was observed and evidence was obtained of a first order phase transition for a non extensive particle system. This HIC phase transition has been identified in previous studies with several signatures, namely Campi scattered plotts [10] as well as fragment size distribution power laws [11].

4 Conclusions.

Once LATINO dynamical model was applied, higher order charge correlations provided computational evidence about the spinodal decomposition in the early stage of fragmentation for central HIC Ni+Ni at intermediate energies. This confirms previous evidence reported by others of a fosil spinodal decomposition, indicating liquid-gas coexistence and a first

order phase transition for non extensive central HIC Ni+Ni. Authors are grateful for the hospitality of the Instituto de Física at UNAM. A.B. acknowledge partial funding from UAM-A and ready acces to the computational resources of the Intensive Computing Lab at UAM-A. Work supported by National Science Foundation (PHY-96-00038).

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