

The study of Heavy-Ion Collisions (HIC) at Fermi energies represents a unique opportunity to probe in laboratory the properties of nuclear matter in several conditions of density, temperature and asymmetry. Actually this investigation allows one to learn about the corresponding behaviour of the nuclear effective interaction, which provides the nuclear Equation of State (EoS) in the equilibrium limit.

Nowadays a particular interest is devoted to the EoS of asymmetric nuclear matter (asy-EoS), whose density dependence is still rather poorly known, except at saturation, since few experimental constraints exist. We stress that the knowledge of the asy-EoS is of fundamental importance for the understanding of many questions of both nuclear physics and astrophysics, including the structure and stability of exotic nuclei, the nature and evolution of neutron stars and the mechanism of supernovae explosion.

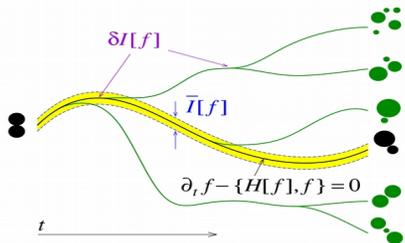
Informations on the EoS can be extracted from the experimental observables by means of a comparison with the theoretical predictions offered by transport models.

In the framework of self-consistent mean-field theory a transport approach, suitable for modeling nuclear reactions in the Fermi energy domain, comes from the Boltzmann-Langevin (BL) equation:

$$\dot{f} = \frac{\partial f}{\partial t} + \{f, H[f]\} = \bar{I}[f] + \delta I[f],$$

where f is the one-body distribution function in phase-space, which is the semi-classical analog of the Wigner transform of the one-body density matrix,

$H[f]$ is the effective mean-field Hamiltonian and the r.h.s. introduces the residual interaction, containing the average Boltzmann two-body collision integral $\bar{I}[f]$ and the fluctuating term $\delta I[f]$. The effect of the fluctuation term on the dynamical trajectories is the possible appearing at any time, whenever the system presents instabilities, of bifurcation branches which



propagate in phase space.

In this thesis, the BL dynamics has been implemented by means of a novel stochastic transport model, the Boltzmann-Langevin One-Body (BLOB) model. Its main feature consists in constructing a stochastic collision term which includes fluctuations in full phase space, as in semiclassical test-particle-based transport approaches.

With this new strategy, the binary collision does not act on two test particles a and b , but it rather involves extended phase-space agglomerates of test particles, A and B , to simulate nucleon wave packets. The collision term is given by:

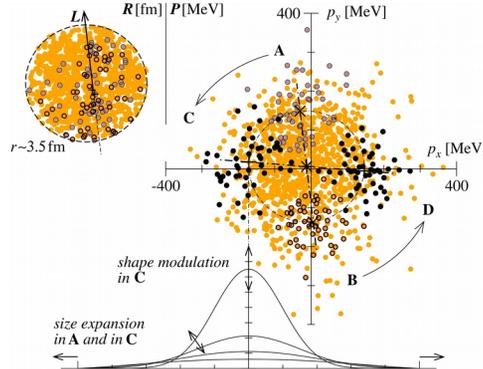
$$\bar{I}[f] + \delta I[f] = g \int \frac{dp_b}{h^3} \int d\Omega W(AB \leftrightarrow CD) F(AB \Rightarrow CD),$$

where the transition rate $W(AB \leftrightarrow CD)$ is the average of the elementary transition rates $W(ab \leftrightarrow cd)$ over the ensemble of all the couples of test particles belonging to the agglomerates A and B ; and the Pauli blocking factor is:

$$F(AB \Rightarrow CD) = (1 - f_A)(1 - f_B) f_C f_D - f_A f_B (1 - f_C)(1 - f_D).$$

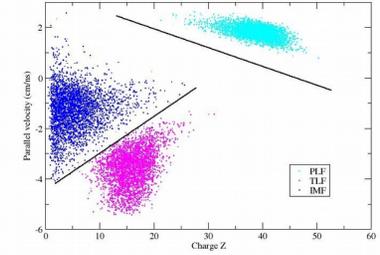
The main advantage of the BLOB model, with respect to the previous attempts to solve the BL equation, lies in the more accurate check of the Pauli exclusion principle, which is realized also thanks to a final shape-modulation procedure, which ensures that the occupancy distribution does not exceed unity in any phase-space point in the final states. This leads to a correct Fermi statistics for the distribution function f , in term of mean value and variance.

In this work BLOB has been employed to investigate a particular fragmentation process, occurring in semi-



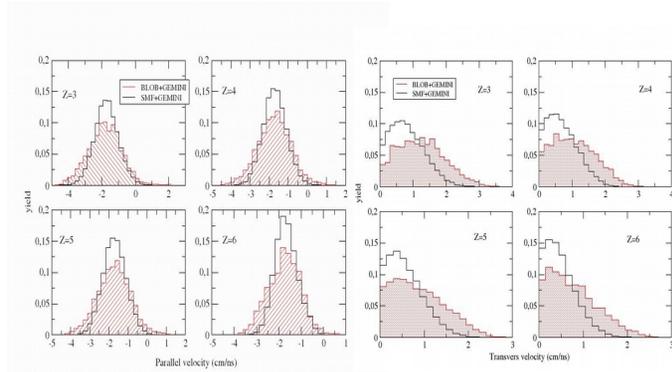
peripheral collision at Fermi energies, i.e. the *neck fragmentation*. Phenomenologically such reactions are characterized by the presence of a non-statistical emission of intermediate mass fragments (IMFs) in the mid-rapidity region between the residues of the initial colliding nuclei, which act as spectators. In a possible reliable scenario, which may explain the observed reaction dynamics, a dilute neck-like structure develops in the overlapping area between the two spectators and then it rapidly separates into fragments, due to the volume and surface instabilities of such excited cylindrically-shaped region.

BLOB has proved to be able to reproduce the instability conditions that lead to the fragmentation of the excited neck region.



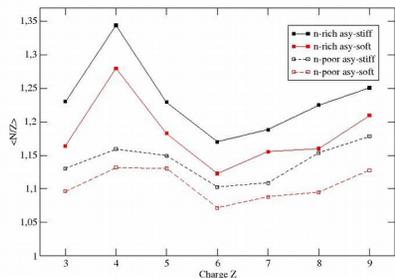
In fact, the analysis of the kinematic properties of the fragments produces a clear scenario in the charge-velocity plane, with three well-separated areas corresponding to projectile-like fragments (PLFs), target-like fragments (TLFs) and IMFs, placed in the mid-velocity region.

Also, the IMF velocity distributions appear to be wider than in previous models, in better agreement with the explosive dynamics observed in experimental data.

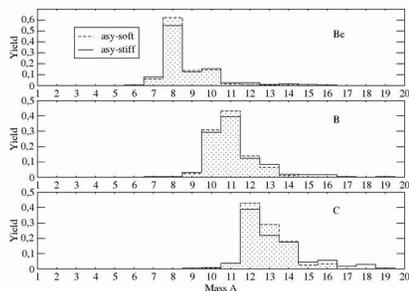


The angular distributions of the neck emitted fragments clearly shown an aligned configuration between the PLF-IMF, and TLF-IMF, system. This indicates a rapid decoupling of the neck fragment from the two residues, and may be interpreted as a signal of a non-statistical production of the IMFs.

Moreover, the isospin transport effects on the isotopic composition of the IMFs is correctly reproduced by BLOB calculations. Since such effects are strictly related to the density dependence of the symmetry energy in sub-saturation conditions, the results obtained by using two parametrizations of the effective symmetry interaction have been compared, named the *asy-soft* and the *asy-stiff* EoS.

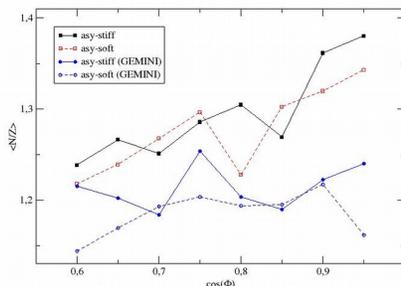


The emerging patterns are consistent with the isospin migration mechanism, according to which a stiffer energy dependence should result in a larger neutron enrichment of the dynamically emitted neck fragments.



In this context a promising observable is represented by the isotopic distributions of the IMFs, where BLOB calculations have pointed out the presence of very exotic isotopes.

In order to further verify the relation between dynamical and isospin effects in the neck region, the isotopic composition of the neck emitted fragments has also been compared to their angular distribution. A correlation between the neutron enrichment of the IMFs and the degree of alignment appears, thus supporting the hypothesis that the same dynamical mechanisms, related to the development of density gradients between the neck region and the spectators and leading to the emission of IMFs, are also responsible of the isospin transport effects.



A comparison between the simulation results and more exclusive experimental data, in order to better investigate fragmentation dynamics and symmetry energy effects, is clearly hoped and, actually, it is already planned for the next future.



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A STOCHASTIC DESCRIPTION OF NUCLEAR REACTIONS AT FERMI ENERGIES

Tesi di Laurea

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