Isospin dependent phase transition

Abstract
The fragmentation phase transition will be quantitatively studied as a function of isospin and charge and located in the phase diagram of asymmetric nuclear matter. Scaling observables from sources differing in charge/isospin will be developed to control data selection criteria. Beam energies overcoming the fragmentation threshold will be needed.

Keywords
Phase transitions, limiting temperature, fluctuations, scaling, calorimetry, heat capacity, statistical properties, correlations

Physics case

Nuclear matter is known to present at least two major phase transitions. A transition to the quark-gluon plasma at high energy density, and a transition to a nucleonic vapour phase a few MeV temperature.
We want to quantitatively settle the low temperature phase diagram of nuclear matter and the characteristics of the expected liquid-gas phase transition. If multi fragmentation experiments in the past 10 years have established approximate values for the temperature, energy and density of this phase change, its nature and order are still largely unknown, as well as its isospin dependence. Studying the transition with finite nuclei has the extra advantage to also allow to evidence the thermodynamic anomalies which should be associated to first order phase transitions of any finite system (negative heat capacity, negative susceptibility, negative compressibility, bimodal distributions). Such signals have already been observed with stable beams and need now to be confirmed and studied as a function of the isospin asymmetry. This physics case has strong interdisciplinary connections with atomic, molecular, and cluster physics. In the framework of EURISOL, we expect important synergies with the Limits of Stability subtask. On the theoretical level, the study of multi-fragmentation with exotic beams has also important astrophysical consequences. Indeed multi-fragmentation is a unique laboratory for the formation of inhomogeneous structures due to Coulomb frustration. Such structures have to be correctly modelized for the supernovae explosion process and the cooling dynamics of proto-neutron stars.

Observables

The main observables needed to characterize the transition and locate it on the phase diagram (ρ_n ,ρ_p) are the energy threshold for fragmentation, temperature measurements, inclusive and exclusive charge scalings, IMF multi-charge correlations, fluctuations, bimodality observables. All these observables one by one bear intrinsic ambiguities and need to be measured at the same time on the same data set.

Proposed experiment

The onset of fragmentation can be established using well developed techniques for stable beams: identification of a fragmentation source, calorimetric measurement, fragment multiplicities and velocity correlations. The change of the fragmentation threshold with the source charge and asymmetry allows to access the charge and asymmetry dependence of level densities, limiting temperature and instability properties. New physics will be searched for looking for scaling violations of fragment observables. The different phase transition signals used for stable beams will be crossed and compared with dedicated simulations to confirm and locate the transition line on the phase diagram.

Requirements:

Beam properties

Different isotopes of medium and heavy beams from neutron poor to neutron rich (e.g. ^{56}Ni -> ^{74}Ni, ^{106}Sn ->^{132}Sn, ^{200}Rn->^{228}Rn) in an energy range 30-100 A.MeV.

Detection

- 4π and low threshold complete A and Z identification for IMF (FAZIA)
- 4π neutron detector
- High angular resolution $\Delta\theta<0.5$ LCP and neutron arrays for correlation measurements

Theoretical support

Extensive realistic simulations of the collision dynamics (HIPSE,MD) will be needed to support data selection criteria. Both microscopic and macroscopic statistical models (LGM,AMD,SMM,MMM) have to be employed to give quantitative predictions on phase transition observables. Dedicated statistical simulations including the experimental constraints have to be developed. A theoretical improvement on evaporation codes for side feeding corrections will be needed.