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Phase diagram of strongly interacting matter and how should we study it in heavy ion collisions

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After almost 40 years of experiments on heavy ion collisions (HIC) the situation with the discovery the new phases of QCD is somewhat paradoxic. On the one hand, we are sure that at highest RHIC energies the partons are created in HIC, but on the other hand, we do not know the answers to three principal questions:
1. At high baryonic charge densities the chiral symmetry restoration and color deconfinement are the same phenomenon or not?
2. At high baryonic charge densities
the chiral symmetry restoration and color deconfinement
are phase transitions or not?
3. What are the collision energy thresholds for these phenomena?

The new experiments on RHIC and the ones planned on the NICA and FAIR will provide us with a lot of experimental data, but, unfortunately, there are strong arguments that with the existing theoretical knowhow it will be impossible to convince ourselves and the colleagues from the other communities that we have clear answers on these principal questions. The problem is not only that we are dealing with small and short living systems in which there are no phase transitions or (tri)critical endpoint in a strict sense of statistical mechanics. The main problem, in my mind, is that our best theoretical tools to model phase transitions, namely the equations of state and the hydrodynamic codes, are not suited to model those small and short living systems. Based on the morphological thermodynamics [1] and its quantum version [2] I argue that it is absolutely necessary to develop the finite volume statistical models for the phase of chiral hadrons, for quark gluon plasma and phase transformations between them.
The best starting point would be exactly solvable models
similar to the quark gluon bags with surface tension [3] which, besides the surface tension coefficient, should also include the curvature tension coefficient (a kind of Tolman correction) and large width of quark gluon plasma bags in spirit of Ref. [4]. Such modifications are necessary, but to develop the realistic equations of state of all QCD phases the input from the lattice formulation of QCD, from the Nambu-Jona-Lasinio model (surface tension) and from the generalized functional renormalization group approach (in-medium width) [5] is of high demand. In addition, it seems that without developing the hydro-kinetic approach for the imaginary values of free energy to treat the metastable states in finite systems. Finally, I will argue that to resolve those principal problems we need to create a theoretical collaboration whose members will concentrate their efforts not on the current fashion(s), but on solving those principal problems.

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