STAR Collaboration Questions for May 14-15 QGP Discussion

To aid a critical evaluation of the evidence regarding QGP formation in RHIC collisions, we would like to see the following questions (among others) seriously discussed during the planned RBRC meeting. After each question, we provide a slightly more detailed context for the question.

1) **The unprecedented success of hydrodynamics calculations assuming ideal relativistic fluid behavior in accounting for RHIC elliptic flow results has been interpreted as evidence for *both* early attainment of local thermal equilibrium *and* a soft equation of state, characteristic of the predicted phase transition. How do we know that the observed elliptic flow can't result, alternatively, from a harder EOS coupled with incomplete thermalization?**

RHIC v_2 results appear to follow smooth trends established by lower-energy heavy ion collisions, but not predicted by hydrodynamics. The hydrodynamic overestimate of elliptic flow at lower energies has generally been attributed to a failure to achieve complete thermalization. This interpretation suggests that the energy-dependence of flow (as well as other) observations is dominated by the poorly understood dynamics of early thermalization, so that the apparent success at RHIC energies should be interpreted cautiously before one sees comparable success at other energies or initial deformations as well. While application of hydrodynamics relies on local thermal equilibrium, it is not evident to us that agreement with data after parameter adjustment necessarily proves thermalization. We are also concerned that answering this question by stating that the EOS is already known from lattice QCD calculations, so that only the degree of thermalization is open to doubt, tends to trivialize the QGP search by presuming the answer.

2) **The indirect evidence for a phase transition of some sort in the elliptic flow results comes primarily from the sensitivity in hydrodynamics calculations of the magnitude and hadron mass-dependence of v_2 to the EOS. How does the level of this EOS sensitivity compare quantitatively to that of uncertainties in the calculations, gleaned from the range of parameter adjustments and the observed deviations from the combination of elliptic flow, spectra and HBT correlations?**

When parameters are adjusted to reproduce spectra, agreement with v_2 measurements in different centrality bins is typically at the 20-30% level. The continuing systematic discrepancies from HBT results and from the energy dependence of elliptic flow suggest some level of additional ambiguity from the freezeout models used and from the assumption of complete local thermal equilibrium. When these uncertainties are fairly treated, does a convincing signal for a soft EOS survive?

3) **Can we make a convincing QGP discovery claim without clear evidence of a phase transition? Can we predict, based on what we now know from SPS and RHIC collisions, at what energies or under what conditions we might**

produce matter below the critical temperature, and which observables from those collisions should not match smoothly to SPS and RHIC results?

The hallmark of QGP formation in lattice QCD calculations, and as sold to the larger physics community for years, is a rapid transition around a critical temperature leading to deconfinement and, quite possibly, chiral symmetry restoration. Can we make a compelling claim to have discovered a new form of matter if we are not yet able to demonstrate convincingly either deconfinement, or chiral restoration, or a rapid transition in some aspect of the collision behavior? If the transition temperature should be reached below RHIC and SPS energies, or in lighter systems or more peripheral collisions, where should it be reached, and how might one see its effects via a non-smooth signal as a function of energy, system size or centrality? Is it conceivable that there is no rapid transition in nature, but just a gradual evolution from dominance of hadronic toward dominance of partonic degrees of freedom? If the latter is the case, is the question of QGP "discovery" well-posed?

4) **Does the magnitude of the parton energy loss inferred from RHIC hadron suppression observations *demand* an explanation in terms of traversal through deconfined matter? The answer must take into account quantitative uncertainties in the energy loss treatment arising, for example, from the uncertain applicability of factorization in-medium, from potential differences (other than those due to energy loss) between in-medium and vacuum fragmentation, and from effects of the expanding matter and of energy loss of the partons through cold matter preceding the hard scattering.**

The parton energy loss treatments do not directly distinguish passage through confined vs. deconfined systems. Evidence of deconfinement must then be indirect, via comparison of the magnitude of inferred gluon or energy densities early in the collision to those suggested by independent partonic treatments such as gluon saturation models. The actual energy loss inferred from fits to RHIC data, through the rapidly expanding collision matter, is only slightly larger than that indicated through static cold nuclei by fits to semi-inclusive deep inelastic scattering data. The significance of the results is then greatly magnified by the correction to go from the expanding collision matter to an equivalent static system at the time of the initial hard scattering. The quantitative uncertainties listed in the question will then be similarly magnified. What, then, is a reasonable guess of the range of initial gluon or energy densities that can be accommodated, and how does one demonstrate that those densities can only be reached in a deconfined medium?

5) **If there is a truly universal gluon density saturation scale, determined already from HERA e-p deep inelastic scattering measurements, why has it been necessary to refit parameters of the saturation scale to RHIC A+A particle multiplicities? Is not the A-dependence of the gluon densities at the relevant Bjorken x-ranges predicted in gluon saturation treatments?**

The gluon saturation models set a QCD scale for anticipated gluon densities, that can then be compared to values inferred from parton energy loss treatments, modulo the questions asked in number (4) above. Can't this scale be predicted based on measurements independent of RHIC? If the scale is fit to observed RHIC multiplicities, is it providing truly independent information from those extracted via the old Bjorken scenario from measured rapidity densities?

6) **Coalescence models have provided a simple ansatz to recognize the possible importance of constituent quark degrees of freedom in the hadronization process in A+A collisions at RHIC, and to suggest that these constituent quarks exhibit collective flow. Aside from providing an organizing principle to appreciate the observed ratios of yields and elliptic flow strengths for baryons vs. mesons, what predictive power do these models have? Can they predict the centrality-dependence of these ratios, or meson vs. baryon correlations (angular or otherwise) at moderate p_T?**

In the p_T region where coalescence models have been claimed to account for a substantial fraction of the observed hadrons, observed two-particle angular correlations show a clear jet-like peak apparently characteristic of a hard parton fragmentation mechanism, though with greater breadth in pseudorapidity than in azimuthal difference for central collisions. Can these features (including the level of background that exhibits only elliptic flow azimuthal correlations) be understood quantitatively in a 2-component model attributing the yields of baryons and mesons to a mixture of coalescence and fragmentation? Can the same treatment predict the balance function in this moderate p_T region?