## Probing the microscopic properties of quark-gluon plasma by transport phenomena

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Transport processes, such as the flowing of water, transfer of heat, or conduction of electric charge, are common phenomena in physics. On a microscopic level, they provide a window into the underlying many-body physics of the system. In the context of quark-gluon plasma (QGP) research using high-energy heavy-ion collisions, the bulk evolution of the matter can be described by hydrodynamics, while, within this background, the transport of heavy quarks can be described as a Brownian (diffusive) motion. The pertinent transport coefficients — shear viscosity for hydrodynamics and the drag/diffusion coefficients for the heavy-quark (HQ) diffusion — can be constrained by experiments and ultimately allow us to extract the microscopic information such as spectral properties and the underlying color force in the QGP. In particular, the transport properties can help us to distinguish between weakly coupled and strongly coupled scenarios of the QGP. Using a selfconsistent many-body approach, we found that both scenarios are consistent with lattice-QCD data on the equation of state and heavy- quarkonium correlators [1, 2], see Fig. 1. In this contribution, we analyze the shear viscosity and HQ transport coefficients in both scenarios.

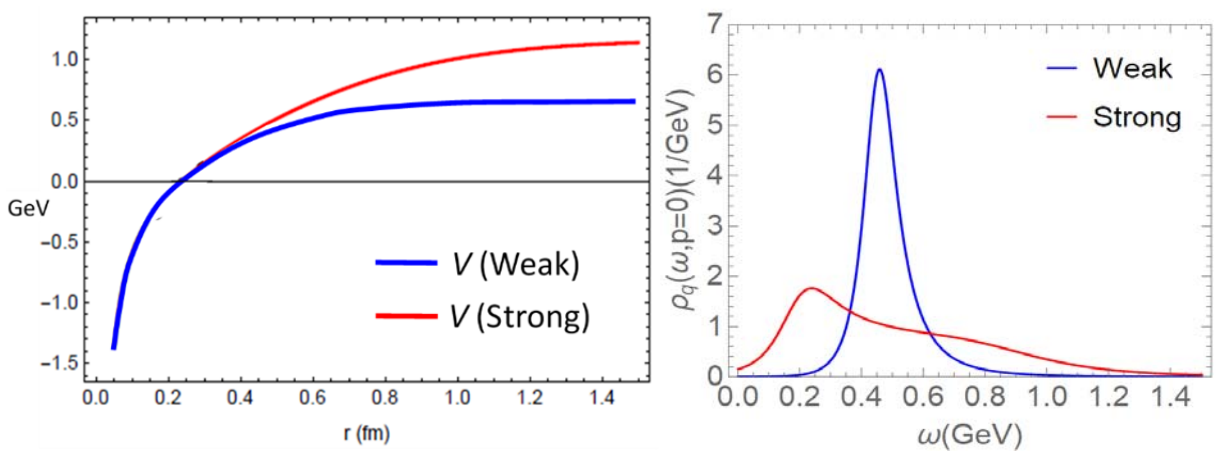


**FIG. 1**. Color singlet potentials (left panel) and pertinent spectral functions (ight panel) and for WCS and SCS at T=194MeV.

To evaluate the HQ friction coefficient, we extend previous *T*-matrix calculations [3] to include the off-shell effects as described in Refs. [1, 4], Schematically, one has

$$\mathrm{A(p)} = \langle\left(1 - \frac{\mathbf{p}\cdot\mathbf{p}'}{p^2}\right)\rho_i\rho_i\rho_c\rangle$$

where $\rho_{i(c)}$ are spectral functions for light partons (charm quark) and $\mathbf{p}(\mathbf{p}')$ denotes the incoming (outgoing) charm-quark momentum. The spatial diffusion coefficient is defined as $D_s = T/(A(0)M)$. For the shear viscosity, $\eta$, a Kubo formula is employed at the (dressed) one-loop level [1]

$$\eta = \lim_{\omega\to 0}\sum_i \frac{\pi d_i}{\omega}\int \frac{d^3\mathbf{p}}{(2\pi)^3}\frac{p_x^2 p_y^2}{\varepsilon_i^2(p)}\rho_i(\omega+\lambda,p)\rho(\lambda,p)[n_i(\lambda)-n_i(\omega+\lambda)]$$

where $d_i$ and $n_i(\omega)$ are the partons' degeneracies and thermal distribution functions, respectively. The results of the transport coefficients from a weakly-coupled scenario (WCS) and a strongly coupled scenario (SCS) found in Refs. [1, 2] are shown in Fig. 2. The dimensionless quantities $D_s(2\pi T)$ and $4\pi\eta/s$ characterize the interaction strength of the bulk medium (with smaller values indicating stronger

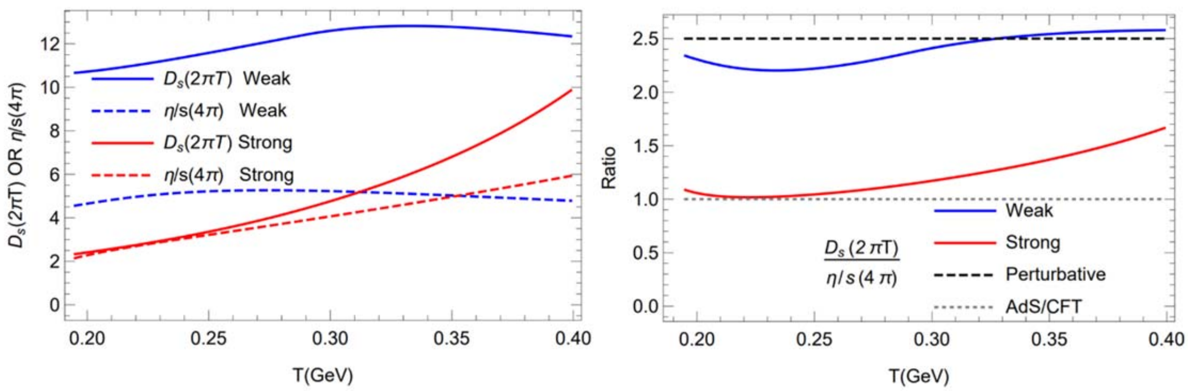


**FIG. 2**. Spatial diffusion coefficient, $2\pi TD_s$, and the ratio of shear viscosity to entropy density, $4\pi\eta/s$, for WCS (blue lines) and SCS (red lines) (left panel), and their ratio $[2\pi TD_s]/[4\pi\eta/s]$ (right panel).

coupling). For the SCS both transport coefficients are within a factor of two of the conjectured quantum lower bounds of one, and increase with temperature indicating a transition to a more weakly coupled medium. On the contrary, for the WCS both transport coefficients are significantly larger and rather constant with temperature. In an attempt to better quantify the notions of "strongly" and “weakly" coupled media, one can inspect the ratio for the two dimensionless transport coefficients discussed above. In particular, the ratio r ≡ $[2\pi TD_s]/[4\pi\eta/s]$ is expected to be near one in the strong-coupling limit, while perturbative estimates appropriate for a weakly coupled system result in ~5/2. We plot this ratio in the right panel of Fig. 2 for both the SCS and WCS. Interestingly, for the SCS the ratio is around one for low temperatures, slowly increasing with temperature but still significantly below 5/2 at T=400 MeV. On the contrary, for the WCS the ratio is close to 5/2 characteristic for a weakly coupled system even at low temperatures, with insignificant temperature dependence. Implementing the HQ transport coefficients into the Langevin simulation (Brownian motion) [4], we found the experimental results to strongly prefer the SCS.

In summary, within the thermodynamic T-matrix approach, we have calculated transport coefficients of the QGP — shear viscosity and diffusion coefficient — within weakly and strongly coupled scenarios, which turn out to be markedly different. Implementing them into transport simulations to compare with experimental results, we conclude that the QGP must be strongly coupled and that its microscopic properties are characterized by a long-range color force with spectral functions that exhibit a transition from melting parton spectral functions to emerging hadronic bound states as the phase transition temperature is approached from above [1,2,4].

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