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QGP viscosity coefficients: from weak to strong coupling

Introduction

The observation that the quark-gluon plasma (QGP) formed in high-energy nuclear collisions behaves almost like a perfect fluid inspired many efforts to quantify the QGP transport properties. The **ratio of bulk to shear viscosity** is expected to exhibit a different behavior in weakly and in strongly coupled systems. This can be expressed by the dependence of the ratio on the squared sound velocity. In the high temperature QCD plasma at small running coupling, the viscosity ratio is uniquely determined by a *quadratic dependence* on the **conformality measure**, whereas in certain strongly coupled and nearly conformal theories this dependence is *linear*. Here, the QGP is considered as composed of *quasi-particle excitations* with *medium-modified* dispersion relations (*self-energies*).

Effective kinetic theory

Assuming that the kinetics of the quasi-particles is described by *effective kinetic equations of Boltzmann-Vlasov type*, self-consistency of the approach dictates the form of the Vlasov-terms, i.e. in local thermal equilibrium they must be related to the temperature dependence of the self-energies. The derived expressions for shear and bulk viscosities for one-component systems read [1,2]

$$\eta = \frac{1}{15T}\int \frac{d^3\vec{p}}{(2\pi)^3} n(T)[1+d^{-1}n(T)]\frac{\tau}{(E^0)^2}\vec{p}^{\,4}\,, \quad (1)$$

$$\zeta = \frac{1}{T}\int \frac{d^3\vec{p}}{(2\pi)^3} n(T)[1+d^{-1}n(T)]\frac{\tau}{(E^0)^2}\left\{\left[(E^0)^2-a\right]v_s^2-\frac{1}{3}\vec{p}^{\,2}\right\}^2, \quad (2)$$

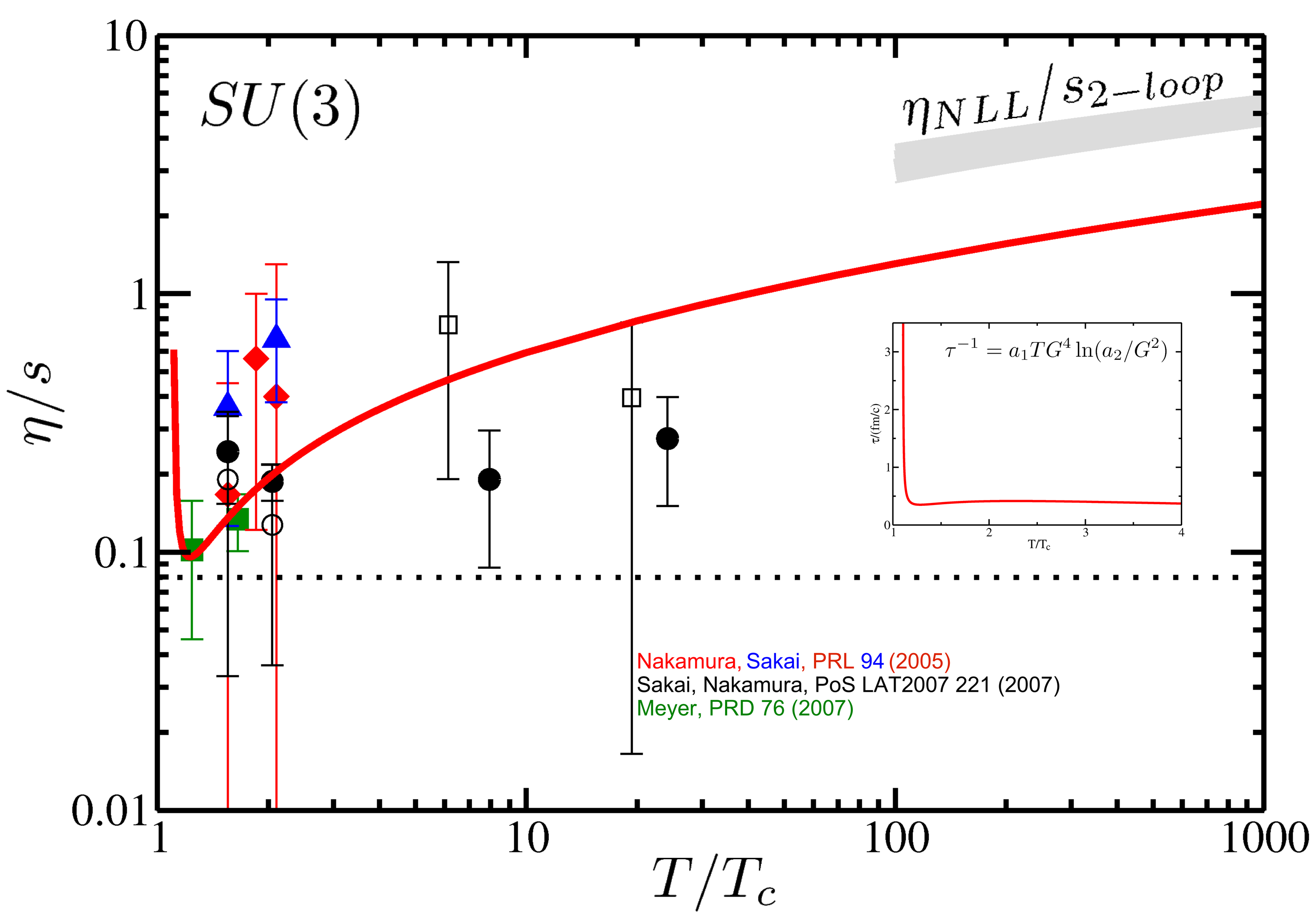
where T is the temperature, $n(T)$ the distribution function, τ the relaxation time, E^0 the quasi-particle energy, d the degeneracy factor, v_s^2 the squared speed of sound and $a=T^2(\partial\Pi/\partial T^2)$ with self-energy Π. To quantify the transport coefficients and to compare with available lattice QCD results, we employ for the **gluon** self-energy the ansatz

$\Pi(T)=T^2G^2(T)/2$

with temperature dependent effective coupling

$$G^2(T)=\frac{16\pi^2}{11\ln[\lambda(T-T_s)/T_c]^2}\,.$$

The comparison with lattice QCD is shown in the left panel [3,4].



Ratio of bulk to shear viscosity

From expressions (1) and (2) one obtains for the ratio [5]

$$\frac{\zeta}{\eta}=15\left(\Delta v_s^2\right)^2-30\,\Delta v_s^2\,(\Pi-a)\,v_s^2\frac{\mathcal{I}_0}{\mathcal{I}_{-2}} +15(\Pi-a)^2\left(v_s^2\right)^2\frac{\mathcal{I}_2}{\mathcal{I}_{-2}}$$

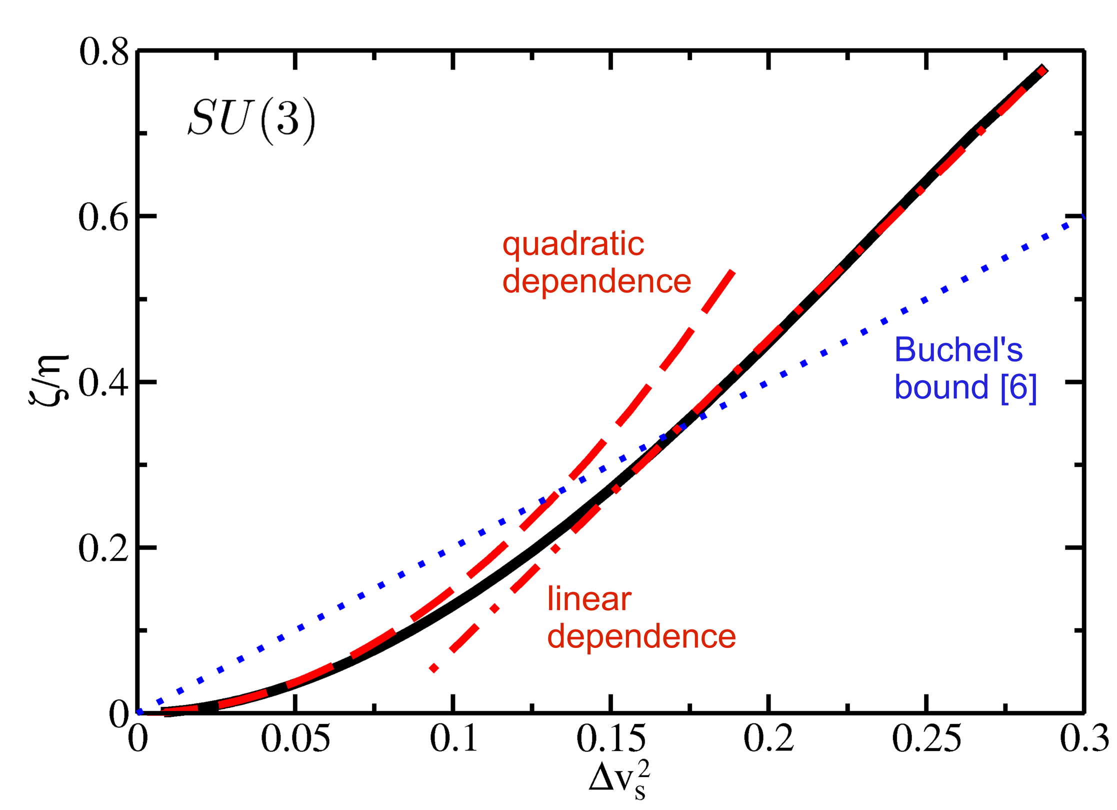
with momentum integrals

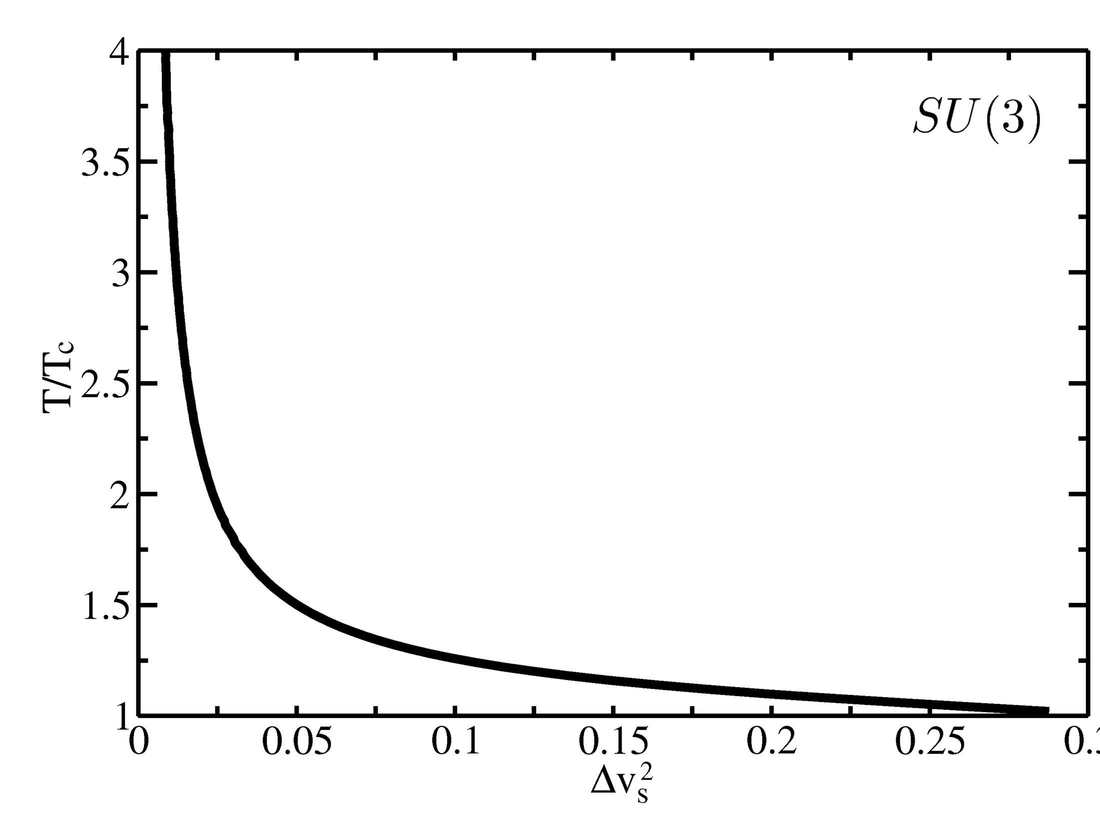
$$\mathcal{I}_k=\int\frac{d^3\vec{p}}{(2\pi)^3}n(T)[1+d^{-1}n(T)]\frac{\tau}{(E^0)^2}\vec{p}^{\,2-k}\,.$$

The ratio has terms quadratic and linear in and independent of the conformality measure $\Delta v_s^2=1/3-v_s^2$.
A quadratic dependence is known from perturbative QCD, while a linear dependence is known from specific strongly coupled and nearly conformal theories that allow for a holographically dual supergravity description. At **asymptotic temperatures**, the *leading terms* of the squared sound velocity read

$$v_s^2=\frac{1}{3}+\frac{5}{36}bT\frac{dG^2}{dT}+\mathcal{O}\left(G^2T\frac{dG^2}{dT}\right),$$

while *in the vicinity of the deconfinement temperature* $v_s^2\rightarrow 0$.





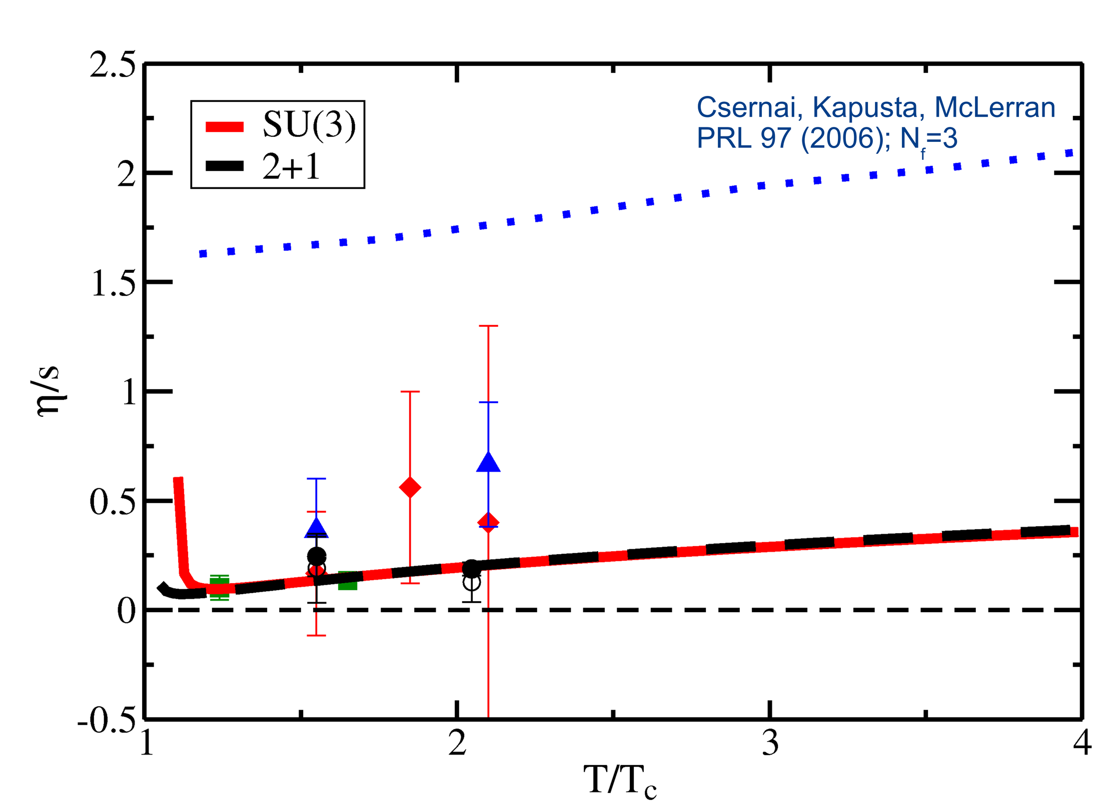
At **asymptotically large temperatures**, *all terms* in the ratio depend quadratically on the conformality measure due to the form of the squared speed of sound in this regime. However, in the vicinity of the deconfinement temperature, the contributions linear in and independent of Δv_s^2 become quantitatively more important (cf. Figs.) and the ratio exhibits clearly a linear dependence. Thus, our quasi-particle approach provides a **systematic interpolation** between the regimes of weak and strong coupling.

Estimates for the QGP

The inclusion of quark degrees of freedom into our approach is mandatory for any phenomenological application at RHIC or LHC.
Assuming relations between the gluon and quark sectors known from perturbative QCD for the shear viscosity to hold also in phenomenologically relevant regions, a **leading order estimate** for the specific shear viscosity of the QGP is given by $\eta=\eta_g+\eta_q$ with

$$\eta_q\simeq 2.2\frac{(1+11N_f/48)}{(1+7N_f/33)}N_f\eta_g\,.$$

Even though both entropy density and shear viscosity increase for the QGP compared to pure SU(3), their ratio is rather robust (cf. Fig.).



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