Multi-component dissipative hydrodynamics.

A. El[1], I. Bouras[1], F. Lauciello[1], Z. Xu[1,2] and C. Greiner[1]

[1]Goethe Universität, Frankfurt am Main;
[2]Frankfurt Institute for Advanced Studies, Frankfurt am Main

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Motivation

Dissipative hydrodynamics has become a standard approach to describe the QGP dynamics. However, QGP is a multi-component system with quark and gluon degrees of freedom, whereas most of the applied hydrodynamic formalisms are given in a one-component formulation.

We address the question to what extent a multi-component system can be described by a one-component formalism with only one transport coefficient (the total shear viscosity).

Using a novel dissipative hydrodynamic formalism for multi-component systems [1] and the kinetic transport model BAMPS [2] we demonstrate that it is necessary to use a multi-component formulation of dissipative hydrodynamics to describe the global dynamics of QGP, since its components in general have different characteristic mean free path scales. One-component hydrodynamics is a special case (long time limit) of the multi-component formalism.

Hydrodynamic Equations

We consider a one-dimensional setup with transverse isotropy and longitudinal homogeneity: all spatial gradients vanish, total energy density e is constant.

One-component system:

The standard Israel-Stewart equation for the shear pressure π is (in LRF)

$$\dot{\pi} = -\underbrace{\frac{2}{9}\frac{e}{\eta}}_{\tau_\pi^{-1}} \cdot \pi = -\frac{5}{9} n\sigma \cdot \pi \qquad (1)$$

η is the shear viscosity coefficient, σ – isotropic elastic cross section.

Two-component mixture:

The equations for the partial shear pressures π_1 and π_2 are [1]

$$\dot{\pi}_1 = -\pi_1 \cdot \left(\frac{5}{9} n_1\sigma_{11} + \frac{7}{9} n_2\sigma_{12}\right) + \frac{2}{9}\pi_2 \cdot (n_1\sigma_{12}) \qquad (2)$$

$$\dot{\pi}_2 = -\pi_2 \cdot \left(\frac{5}{9} n_2\sigma_{22} + \frac{7}{9} n_1\sigma_{12}\right) + \frac{2}{9}\pi_1 \cdot (n_2\sigma_{12}) \qquad (3)$$

n_i are particle densities; σ_{ij} are cross sections for ***elastic isotropic scatterings*** of two particles of types i and j $(i, j = 1, 2)$.

(2)+(3) is equivalent to (1) with $\tilde{\eta} = \frac{2}{5} e \left(\frac{\pi_1}{\pi}(n_1\sigma_{11} + n_2\sigma_{12}) + \frac{\pi_2}{\pi}(n_2\sigma_{22} + n_1\sigma_{12}) \right)$

$\tilde{\eta}$ depends on the dynamics via π_i/π, but the shear viscosity η should depend only on σ_{ij}, e and n_i! Thus a limit has to be found in which

$$\tilde{\eta} \longrightarrow \eta(n_i, e, \sigma_{ij}) \qquad (4)$$

This (quasi-) stationary limit is determined by the conditions $\frac{d}{dt}\left(\frac{\pi_1}{\pi}\right) = \frac{d}{dt}\left(\frac{\pi_2}{\pi}\right) = 0$. $\tilde{\eta}$ becomes the **physical shear viscosity**.

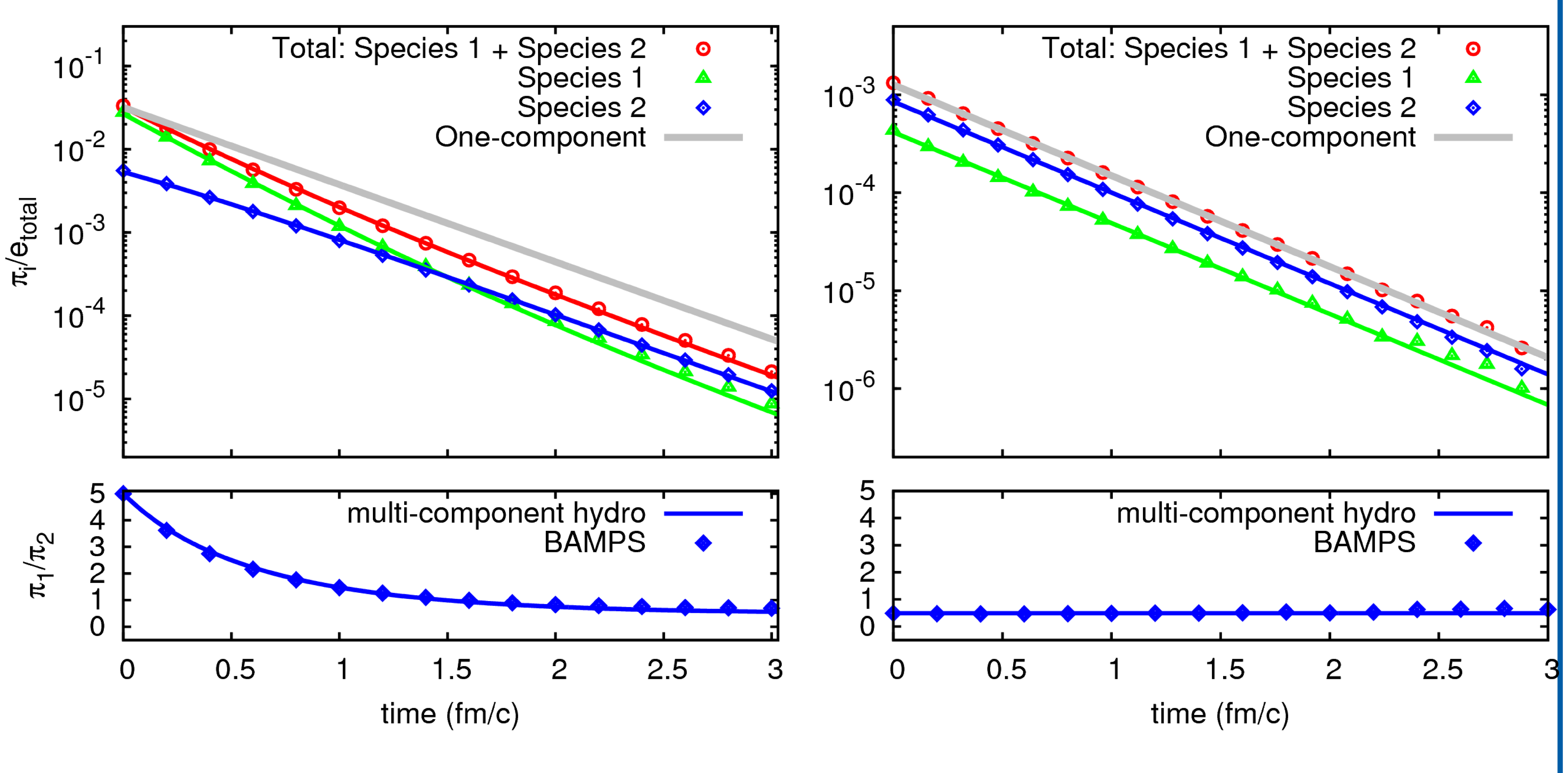
Mixtures in kinetic transport and hydrodynamic approaches

Relaxation of partial shear pressures in **kinetic transport model BAMPS** [2] (Symbols) **multi-component hydrodynamics** [1] (Colored lines) and **one-component hydrodynamics** in $\tilde{\eta} \to \eta$ limit (Grey lines)

$T_1 = T_2 = 400\ MeV$, $\frac{n_1}{n_2} = \frac{e_1}{e_2} = 5$
$\sigma_{11} = 3.88\ mb$, $\sigma_{22} = 0.25 \cdot \sigma_{11}$, $\sigma_{12} = 0.5 \cdot \sigma_{11}$.

For the whole system $\tilde{\eta}/s \to 0.08$.

The initial partial shear pressures are
$\pi_1/\pi_2 = 5$ (Left panel)
$\pi_1/\pi_2 = 0.49$ (Right panel).



Discussion:

Relaxation of the initial anisotropy in BAMPS calculations is accurately reproduced by multi-component hydrodynamic equations. The one-component equation (1) can be applied only after a certain time ($\sim 2.5 - 3\ fm/c$), which is needed to reach the (quasi-) stationary limit and establish a one-component behaviour. If the mixture is initialized according to the (quasi-) stationary limit, one-component hydrodynamic equation becomes applicable immediately.

Conclusions

Applicability of standard one-component hydrodynamic formalisms to mixtures crucially depends on the chosen initial conditions (initial anisotropy, initial time) and the intrinsic microscopic scales in the system (mean free path scales). In oder to describe a mixture accurately by a one-component hydrodynamic formalism, η/s and initial time cannot be chosen arbitrary. Novel multi-component hydrodynamic equations [1] have a wider range of applicability to mixtures and are able to describe both global and component-wise dynamics of the mixture.

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References

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