Competing effects of shear and bulk viscosity within relativistic hydrodynamics

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Introduction

- An event-by-event comparison between shear and bulk viscous effects is done in the 2+1 Lagrangian relativistic hydrodynamical code v-USPhydro [1].
- In this work, we examine both temperature dependent bulk and shear viscosities to entropy density ratio, ζ/s and η/s, respectively, on the anisotropic flow coefficients computed with event-by-event Glauber initial conditions.

Equations of Motion and Parameters

The general expression for the energy-moment tensor that includes both bulk and shear viscosity is

$$T^{\mu\nu} = \varepsilon u^\nu u^\nu - (p+\Pi)\,\Delta^{\mu\nu} + \pi^{\mu\nu}$$

We use for the evolution of the bulk pressure over time [1]

$$\tau_\Pi \left(D\Pi + \Pi\theta\right) + \Pi + \zeta\theta = 0$$

and for the shear stress tensor

$$\tau_\pi \Delta_{\mu\nu\alpha\beta}\frac{D}{D\tau}\pi^{\alpha\beta} + \pi_{\mu\nu} = \eta\Delta_{\mu\nu\alpha\beta}D^\alpha u^\beta \qquad (1)$$

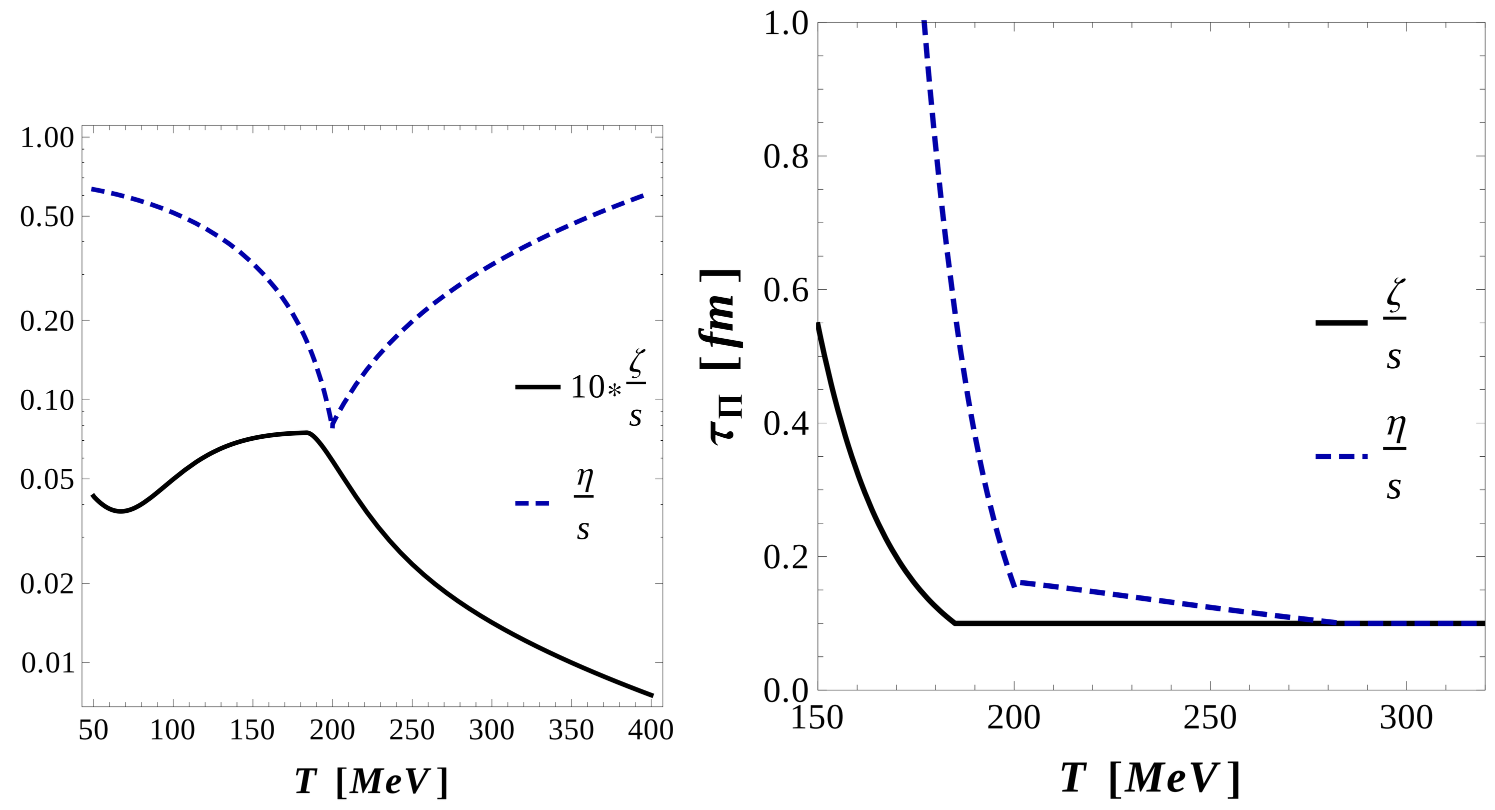
where we use SPH-Smoothed Particle Hydrodynamics [1] (e.g. $s^* = \sum_{\alpha=1}^{N_{SPH}} \nu_\alpha \left(\frac{s}{\sigma}\right)_\alpha W(|\mathbf{r}-\mathbf{r}_\alpha(t)|;h)$).

Parameters:

- SPH scale $h = 0.3$ fm, Initial time $\tau_0 = 1$ fm/c, Isothermal Freeze-out $T_{FO} = 150$ MeV
- Lattice-based EOS [2]
- We choose the transport coefficients [3] as follows

$$\begin{aligned} \eta/s(T<T_c) &= -0.289 + 0.288 * T + 0.0818T^2 \\ (T>T_c) &= 0.681 - 0.0594 * T - 0.544T^2 \\ \tau_\pi &= 5 * \eta/(\varepsilon+p) \end{aligned}$$

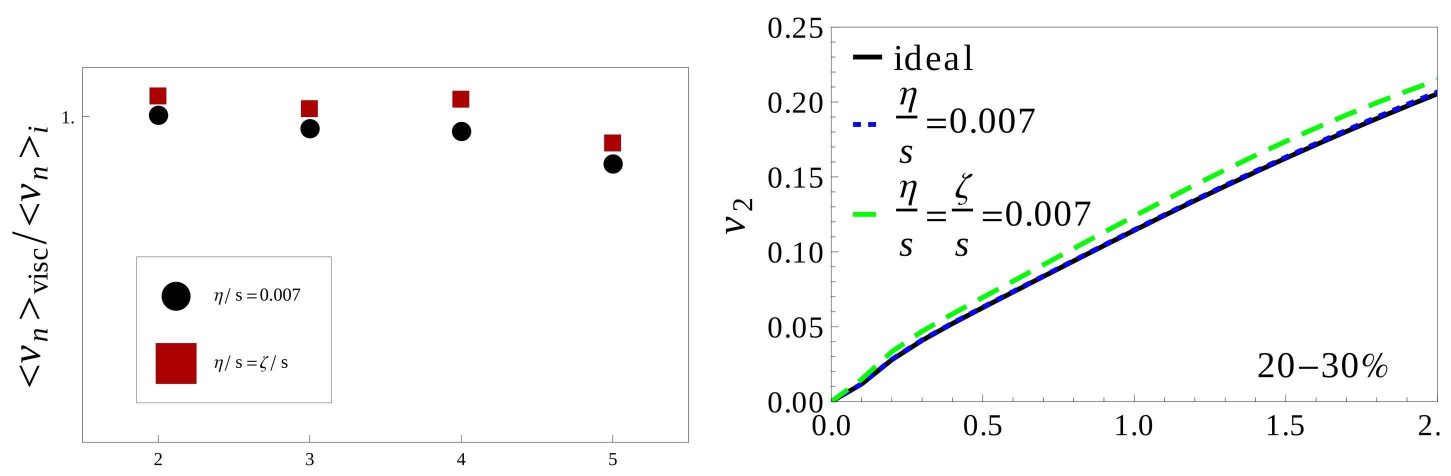
$$\frac{\zeta}{s} = 2\frac{\eta}{s}\left(\frac{1}{3} - c_s^2\right), \qquad \tau_\Pi = 9\frac{\zeta}{\epsilon - 3p}$$



Checks:

- v-USPhydro reproduces the non-trivial analytical solution for shear viscosity within a conformal fluid in [4] for the temperature and all components of the shear stress tensor.
- v-USPhydro also reproduces all the components of the TECHQM viscous test as well as the final gluon spectrum.

$\zeta/s = \eta/s = 0.007$



- When $\zeta/s = \eta/s = 0.007$ the bulk viscosity negates shear effects for integrated v_n's and overcompensates for p_T dependent flow harmonics.

Freeze-out

Single particle distribution function computed within Grad's 14 moment approximation [1]:

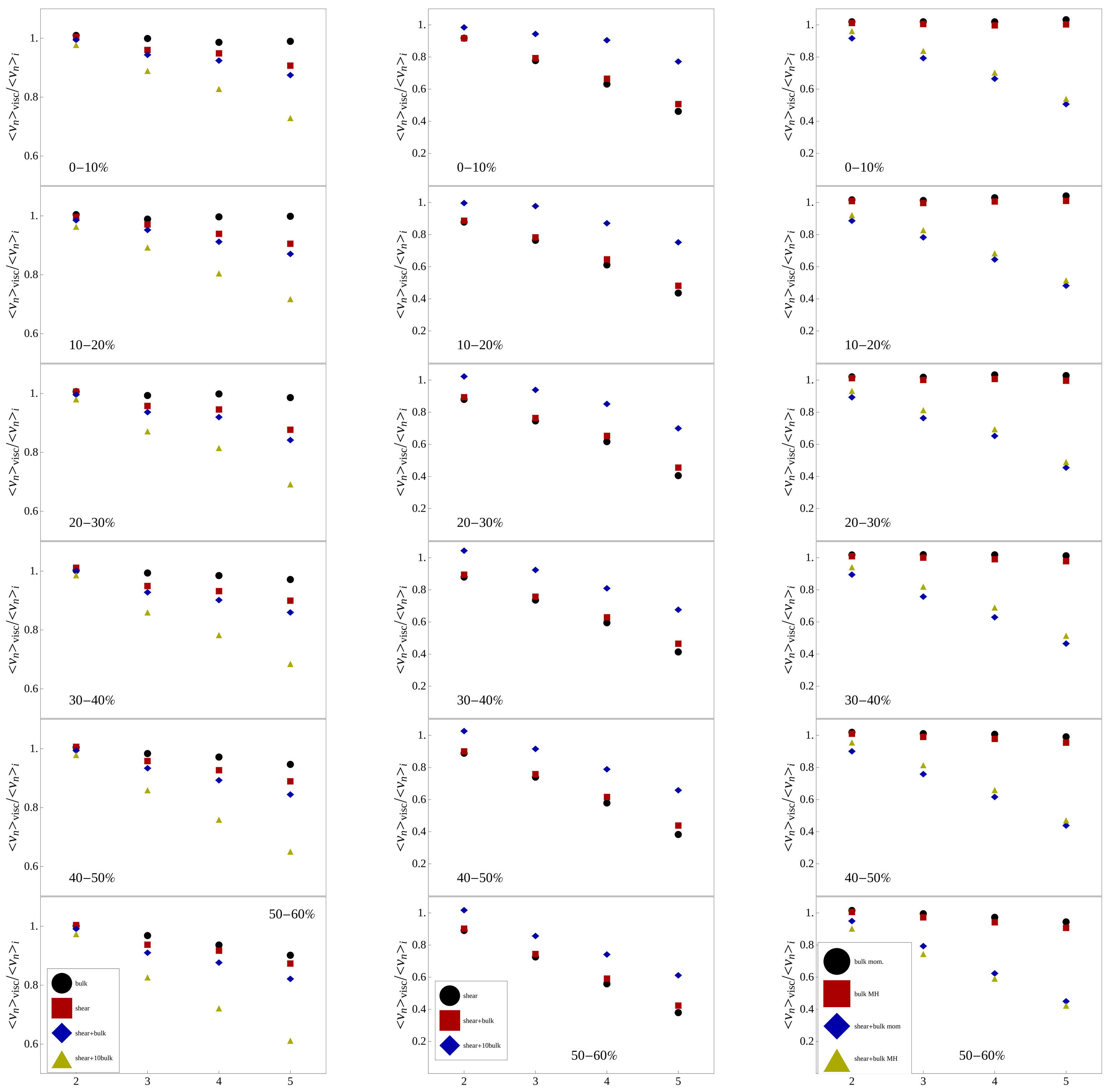
$$f_p^{(i)} = f_{0p}^{(i)}\left\{1 + \left(1 - af_{0p}^{(i)}\right)\left[\Pi\left[B_0^{(i)} + D_0^{(i)}\left(u^i\cdot p_i\right) + E_0^{(i)}\left(u^i\cdot p_i\right)^2\right] + \frac{\eta_i}{\eta}\frac{\pi^{\mu\nu}p_\mu p_\nu}{2\left(\varepsilon_i+P_i\right)T^2}\right]\right\}$$

where $f_0 = \left(\exp[E/T]+a\right)^{-1}$, $a=1$ ($a=-1$) for fermions (for bosons) while $a=0$ for a Boltzmann gas. Moreover, E_0, D_0, and B_0 are nontrivial functions of the particle mass m ($E_p = \sqrt{p^2+m^2}$). and T (mom) [1] or as derived in (MH) [5].

Event-by-Event Glauber Initial Conditions (pions)

- 150 events in each centrality class, Au+Au collisions at RHIC ($\sqrt{s} = 200$ GeV).

no δf_{visc} | δf_{mom} | δf_{mom} vs. δf_{MH}



Conclusions and Outlook

- The interplay between bulk and shear viscosity enhance the viscous effects before viscous corrections to the Cooper Frye freeze-out are considered.
- Integrated v_n's show little dependence on choice of δf correction
- Bulk viscosity may partially compensate for shear viscous effects when they are of the same order of magnitude
- Peripheral collisions are more affected by viscousity for integrated v_n's.

References

[1] J. Noronha-Hostler, G. S. Denicol, J. Noronha, R. P. G. Andrade and F. Grassi, Phys. Rev. C **88**, 044916 (2013)
[2] P. Huovinen and P. Petreczky, NPA **837**, 26 (2010).
[3] J. Noronha-Hostler, J. Noronha and C. Greiner, Phys. Rev. Lett. **103**, 172302 (2009); H. Niemi, G. S. Denicol, P. Huovinen, E. Molnar and D. H. Rischke, Phys. Rev. Lett. **106**, 212302 (2011)
[4] H. Marrochio, J. Noronha, G. S. Denicol, M. Luzum, S. Jeon and C. Gale, arXiv:1307.6130 [nucl-th].
[5] A. Monnai and T. Hirano, Phys. Rev. C **80**, 054906 (2009)