The fragment effects on shear viscosity and liquid-gas phase transition in nuclear plasma

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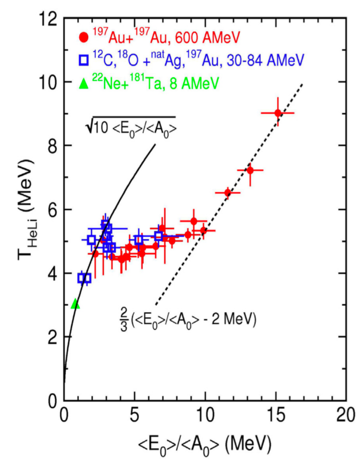
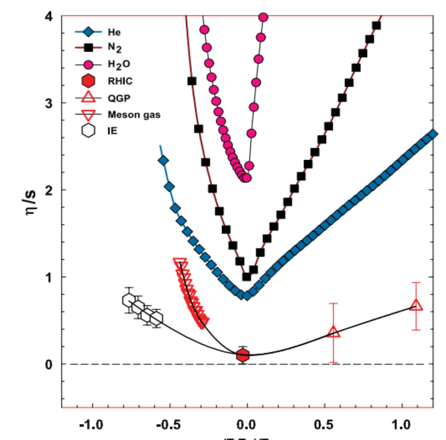
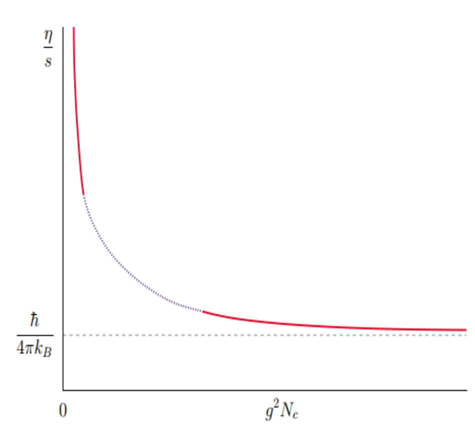
Introduction







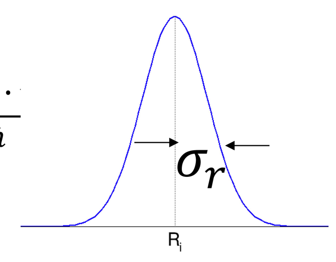
- Liquid-gas phase transition in nuclear matter has been studied in heavy ion collisions for decades[1].
- Shear viscosity is one of most important properties for liquid and gas substances.
- Ratio of shear viscosity to entropy density would be a probe to search the signature of Liquid-Gas phase transition for nuclear matter[2].
- And it is found that the ratio of shear viscosity to entropy density has a limit bound(KSS bound) [3].
- It is interesting to study shear viscosity of nuclear matter .

The ImQMD Model

- There are many transport models to investigate heavy-ion collisions, such as Boltzmann-Uehling-Uhlenbeck model (BUU), Quntum Molecular Dynamic model (QMD).
- QMD model
  - Particles are treated as Gaussian wave packets.
  - Potential is parameterized and Skyrme type interaction.
  - Including three parts: Initialization, evolution and collision.
- An improved quantum molecular dynamic model (ImQMD) is utilized for our simulations.
- In order to imitate infinite nuclear matter, the periodic box is applied in the model.

Gaussian wave packet

$$\psi_i(\vec{r},t) = \frac{1}{(2\pi L)^3}\exp[-\frac{(\vec{r}-\vec{R}_i)^2}{4L} + \frac{i\vec{P}_i\cdot}{\hbar}$$



Wigner density distribution

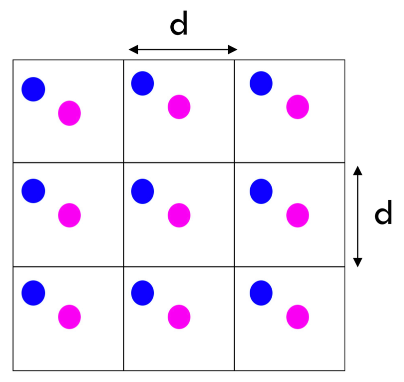
$$f_i(\vec{r},\vec{p},t) = \frac{1}{(\pi\hbar)^3}\exp[-\frac{(\vec{r}-\vec{R}_i(t))^2}{2L} - \frac{2L(\vec{p}-\vec{P}_i(t))^2}{\hbar^2}]$$

$$L = \sigma_r^2;\ \sigma_r\cdot\sigma_p = \hbar/2$$

Potential

$$V_{loc} = \frac{\alpha}{2}\frac{\rho^2}{\rho_0} + \frac{\beta}{\gamma+1}\frac{\rho^{\gamma+1}}{\rho_0^{\gamma}} + \frac{g_{sur}}{2\rho_0}(\nabla\rho)^2 + g_\tau\frac{\rho^{\eta+1}}{\rho_0^{\eta}} + \frac{C_s}{2\rho_0}[\rho^2 - (\nabla\rho)^2]\delta^2$$

Periodic Box

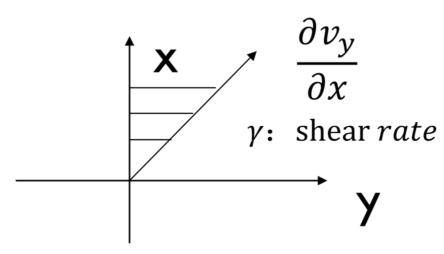


Analysis method

- Shear rate (SSLOD method)

$$\eta = -\lim_{t\to\infty}\frac{<P_{\alpha\beta}(t)>}{\gamma}$$

γ: shear rate; $P_{\alpha\beta}$ is stress tensor

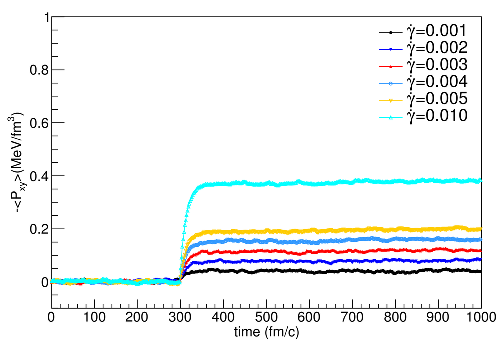


- SSLOD equations-external field

$$\frac{d\vec{r}_i}{dt} = \frac{\vec{p}_i}{m_i} + \gamma y_i\hat{x}$$

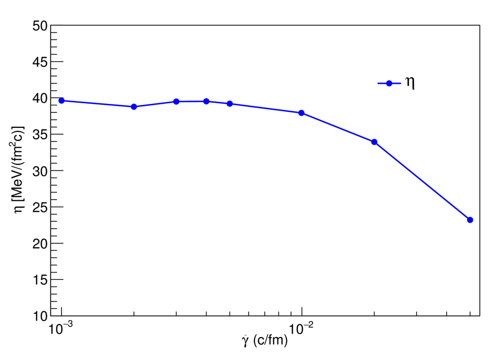
$$\frac{d\vec{p}_i}{dt} = \vec{F}_i - \gamma p_{y,i}\hat{x} - \alpha\vec{p}_i$$

γ is the shear rate and α thermostat multiplier.

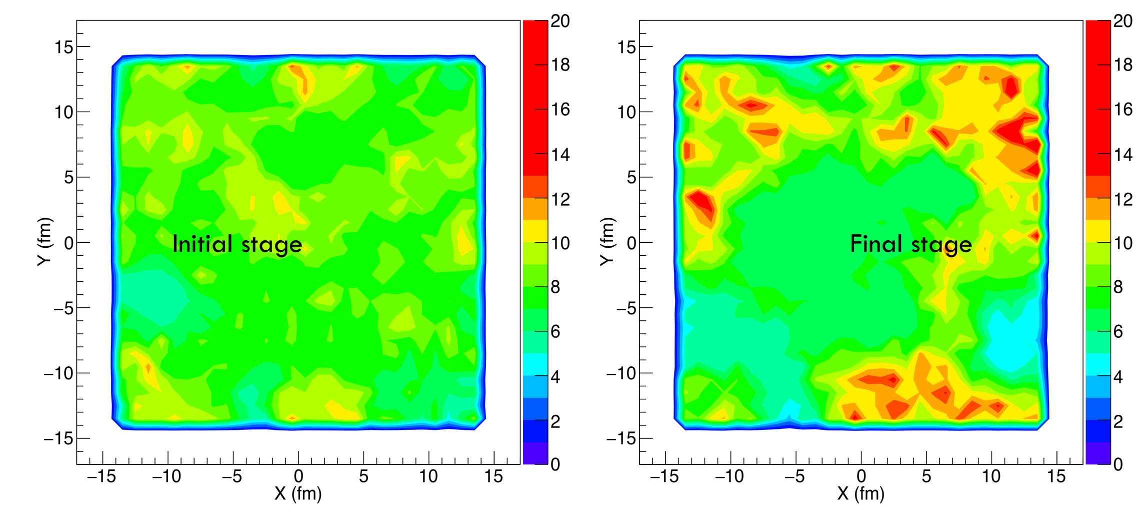


- Thermostat- Gaussian thermostat
  Keeping kinetic energy conserving

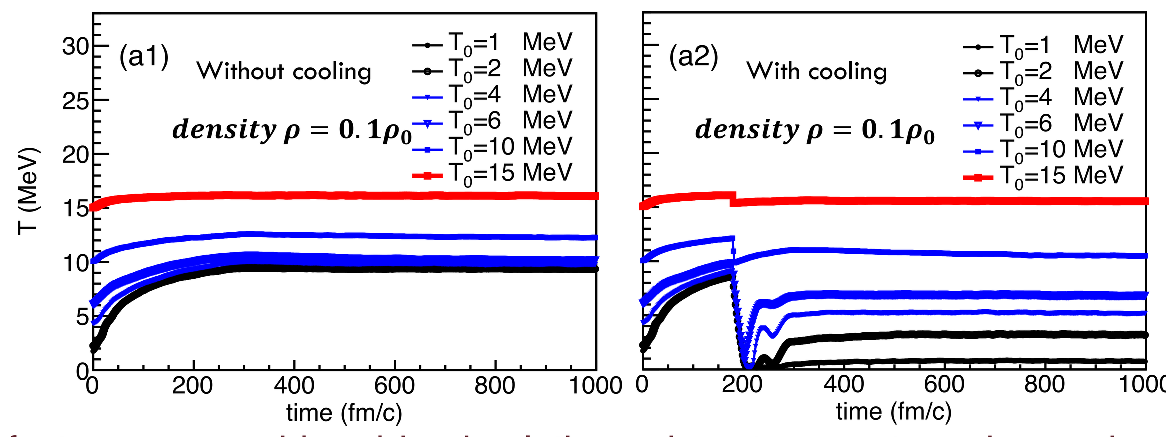
$$\alpha = \frac{\sum_i(\vec{F}_i\cdot\frac{\vec{p}_i}{m_i} - \frac{\gamma p_{x,i}p_{y,i}}{m_i})}{\sum_i\frac{\vec{p}_i^2}{m_i}}$$



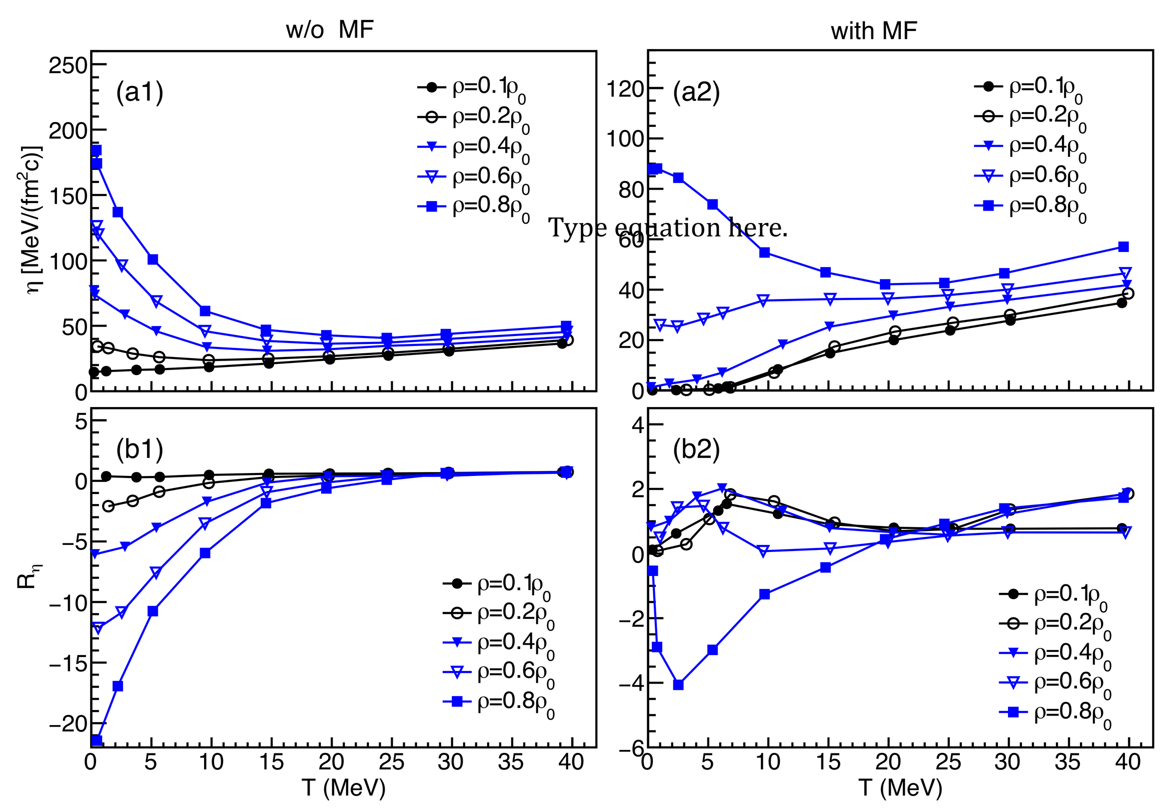
Results and Discussions



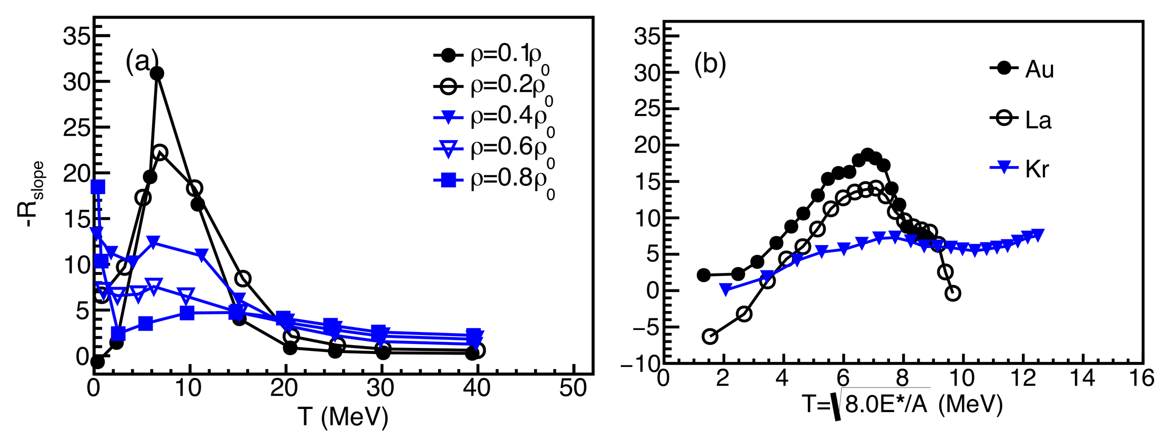
- System is initialized by given particle number, density and temperature. At initial state, it is uniform. As time increasing, if density less than $\rho_0(0.16\ fm^{\wedge}-3)$, fragments or clusters would form in the box due to the potential.



- One cooling factor was considered in simulations since temperature increasing due to fragments forming.



- Without mean field, the system is uniform and void of fragments. In this case, shear viscosity increases as temperature increases at low densities. At higher densities, the initial decrease of the shear viscosity below 10 MeV is due to the Pauli blocking effects.
- Shear viscosity is reduced due to the fragment effects in low temperature region. Even though, the fragments and varies of shear viscosity are essentially caused by the mean field.
- One more thing is that liquid-gas phase transition may occur around 8 MeV.



- Slopes for the largest fragment as a function of temperature are showing in (a). Some peaks were found around 8 MeV.
- The experimental data are showing in (b)[4]. The same behavior between them.

Summary

- We extract the shear viscosity using the SLLOD algorithm by simulating nuclear matter in a box with periodic boundary conditions within the ImQMD model.
- It is found that the inclusion of mean field inter- actions has a great impact on the shear viscosity, due to the fragmentation effects.
- We found critical temperature regions for the shear viscosity, for the ratio of the free nucleons to the IMFs and for the mean mass of the largest fragment. All these critical temperature regions lie be- tweenT =5 MeV and T =10 MeV, which is likely to be tied to the liquid-gas phase transition.

References

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