Electrical conductivity of hot and dense QCD matter: A color string percolation approach

Pragati Sahoo
Indian Institute of Technology Indore

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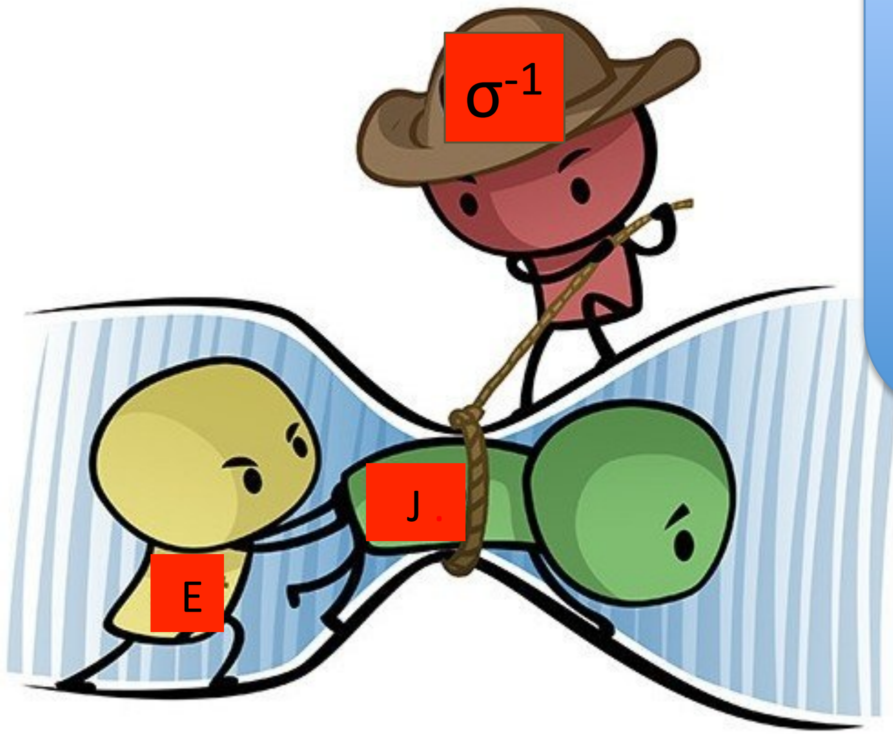
Outline

- **Electrical Conductivity**
- **Color string percolation model (CSPM)**
- **Electrical Conductivity of the QGP**
- **Results**
- **Summary**

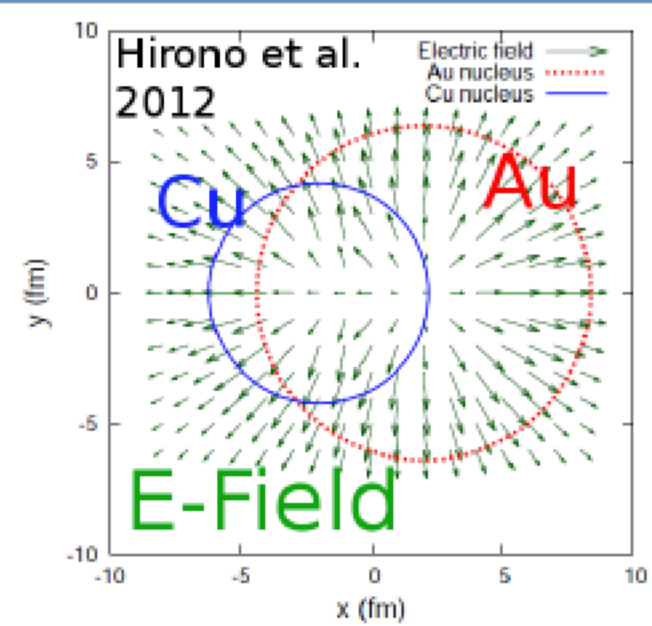
Electrical Conductivity



$$\vec{J} = \sigma_{el}\vec{E}$$

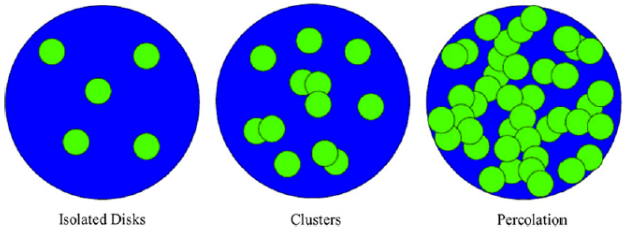
- $\vec{J}$ = electric current density [GeV/fm^2]
- $\vec{E}$ = Electric field [GeV/fm]
- σ_{el} = electric conductivity

"..the charge-dependent directed flow of hadrons is sensitive to the charge dipole in the medium and is useful in estimating the electric conductivity of the QGP."



Color String Percolation Model

What is percolation?



➢ Percolation approach provides both Qualitative picture and Quantitative values for the transition of strongly interacting matter.

3 regimes of nuclear matter density, n ≅ Occupied Vol./Total Vol.

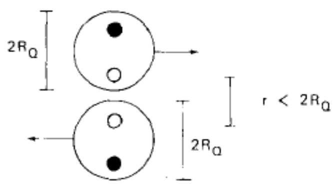


Fig. 1. Hadronic collision.

- No overlap of hadronic volumes
- Free hadron gas
- $n < n_H = 0.48\ n_0$

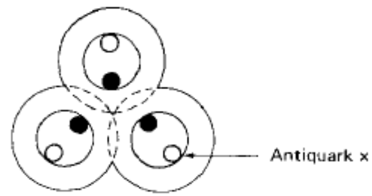


Fig. 2. Hadronic matter.

- Overlapping of hadrons but not in their cores
- Hadronic matter
- $n \geq n_H = 0.48\ n_0$

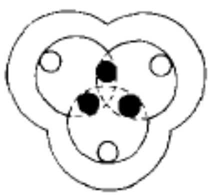


Fig. 3. Quark matter.

- Overlap of hadronic cores
- Quark matter
- $n \geq n_Q = 3.84\ n_0$

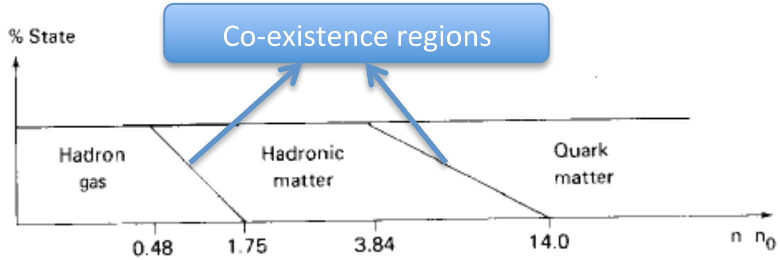


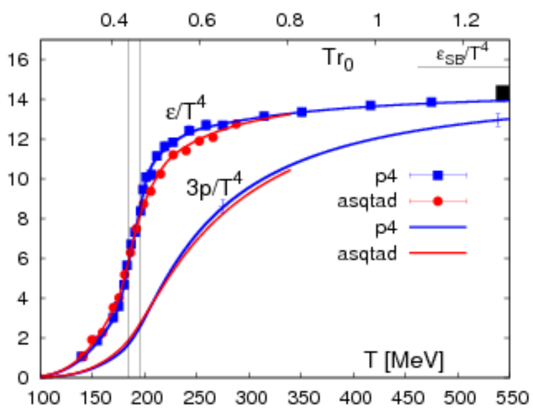
Fig. 4. Strongly interacting matter as a function of density; n_0 = nuclear density.

1. Lower bound and higher bound between two phases says the clustering starts and ceases, respectively.
2. Solidification of hadron gas to hadron solid occur at critical density.
3. There is a critical density from bound to unbound constituents of hadrons.

Color String Percolation Model

- The possible transition of strongly interacting matter from a hadron to a quark state can be treated by percolation theory. [Gordan Baym, Physica 96A (1979)]
- This can be used to investigate the phase structure of the hadronic matter.
- Transport properties of strongly interacting matter, such as electrical conductivity (σ_{el}), shear (η) and bulk viscosities (ζ) are of particular importance to understand the nature of QCD matter along with other thermodynamic and transport properties like: initial energy density (ε), trace anomaly (Δ), the squared speed of sound (C_s^2), entropy density (s) etc.

ε/T^4



P Petreczky, J. Phys. G, 39, 093002

Color String Percolation Model

- Multiparticle production at high energies is described in terms of color strings, stretched between the projectile and target.

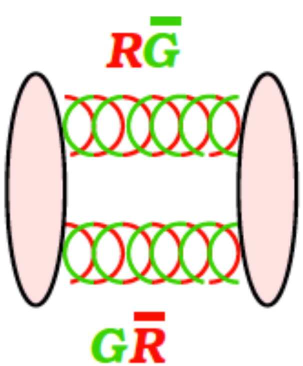
- These strings decay into new strings by production and then subsequently hadronize to produce the observed hadrons.

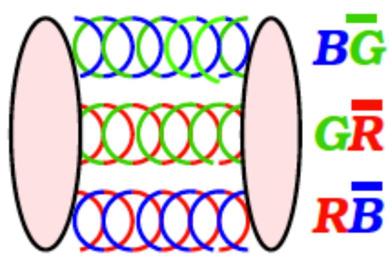
- The no. of strings grow with energy and no. of participating nuclei start to interact and overlap in transverse space as it happens for disks in the 2-D percolation theory.

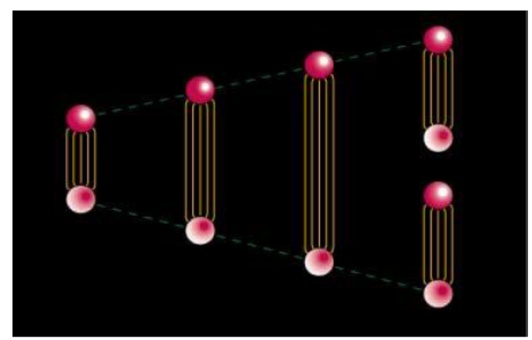
- In heavy-ion collisions, the percolation density parameter (ξ) is given as,

$$\xi = \frac{N^s S_1}{S_N}$$

N^s = # of strings
S_1 = Single string area
S_N = Total overlap area







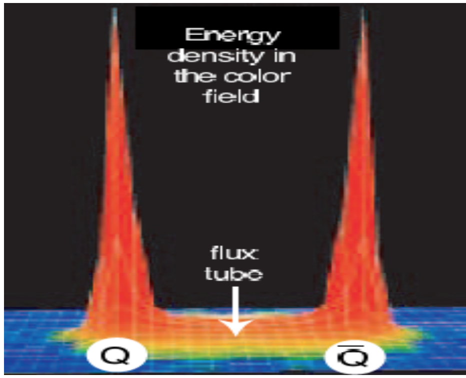
Formulation

Using the p_T spectrum of pp collisions, where there is low string overlap probability, we evaluate the fit parameters,

$$\frac{d^2N}{dp_T^2} = \frac{a}{(p_0 + p_T)^{\alpha}}$$

(a, p_0 and α are the fitting parameters)

To evaluate the interactions of strings in A+A collisions, we use the above parameterization as follows:



$$\frac{d^2N}{dp_T^2} = \frac{a}{(p_0\sqrt{F(\xi)_{pp}/F(\xi)_{AA}} + p_T)^{\alpha}}$$

where, *F(ξ)* is the color suppression factor which reduces the hadron multiplicity from n_0 to the interacting string value.

$$F(\xi) = \sqrt{\frac{1-e^{-\xi}}{\xi}}$$

Temperature is defined as,

$$T(\xi) = \sqrt{\frac{< p_T^2 >_1}{2F(\xi)}}$$

$<p_T^2>_1$ = mean transverse squared of a single string

M. A. Braun and C. Pajares, Eur. Phys. J. C16,349 (2000)
P. Sahoo, S. K. Tiwari, R. Sahoo, Phys. Rev. D 98, 054005 (2018)

Formulation

To calculate the electrical conductivity of strongly interacting matter, the mean free path is used, which describes the relaxation of the system far from equilibrium can be written as,

$$\lambda_{mfp} = \frac{1}{n\sigma_{tr}}$$

n = number density of an ideal gas of quarks and gluons
σ_{tr} = transport cross section

In the CSPM, the number density,

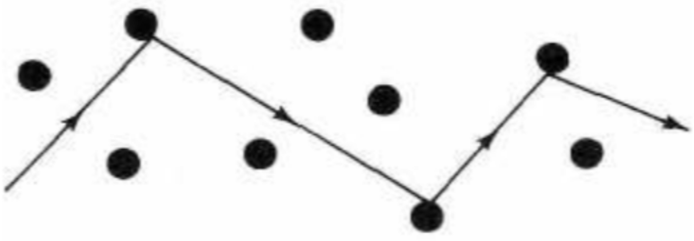
$$n = \frac{N_{sources}}{S_n L}$$

$N_{sources}$ = number of sources per unit volume
L = longitudinal extension of the string ≈ 1 fm

$$N_{sources} = \frac{(1-e^{-\xi})S_n}{S_1 F(\xi)}$$

$$n = \frac{(1-e^{-\xi})}{S_1 F(\xi) L}$$

$$\implies \lambda_{mfp} = \frac{L}{(1-e^{-\xi})}$$



Electrical conductivity

- The Electrical conductivity in the relaxation time approximation is,

$$\sigma_{el} = \frac{1}{3T}\Sigma_{k=1}^{M} q_k^2 n_k \lambda_{mfp}$$

- Considering the density of the up quark (u) and its antiquark (ū),

$$\sigma_{el} = \frac{1}{3T}\frac{4}{9}e^2 n_q(T)\frac{L}{1-e^{-\xi}}$$

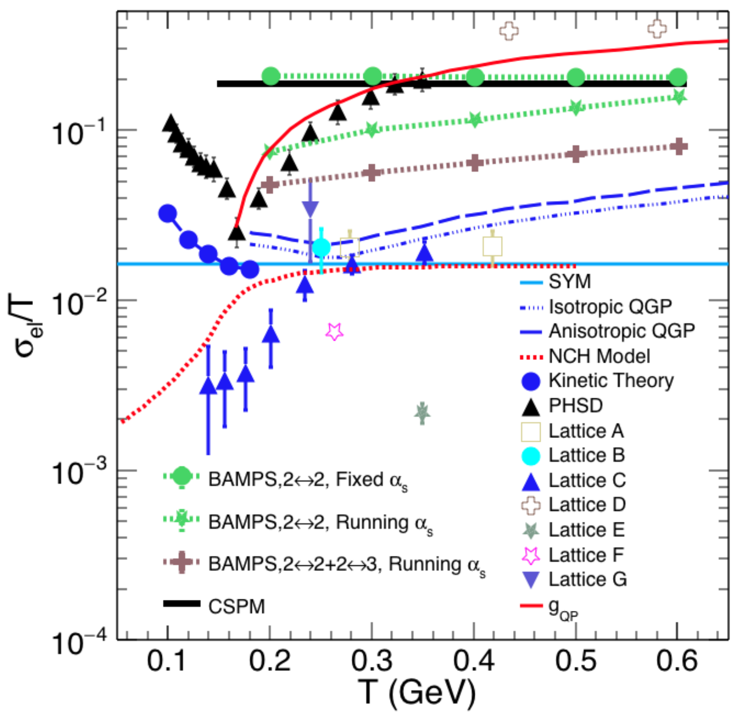
- Here, λ_{mfp} = mean free path of partons, n_q = number density, e = charge of partons.

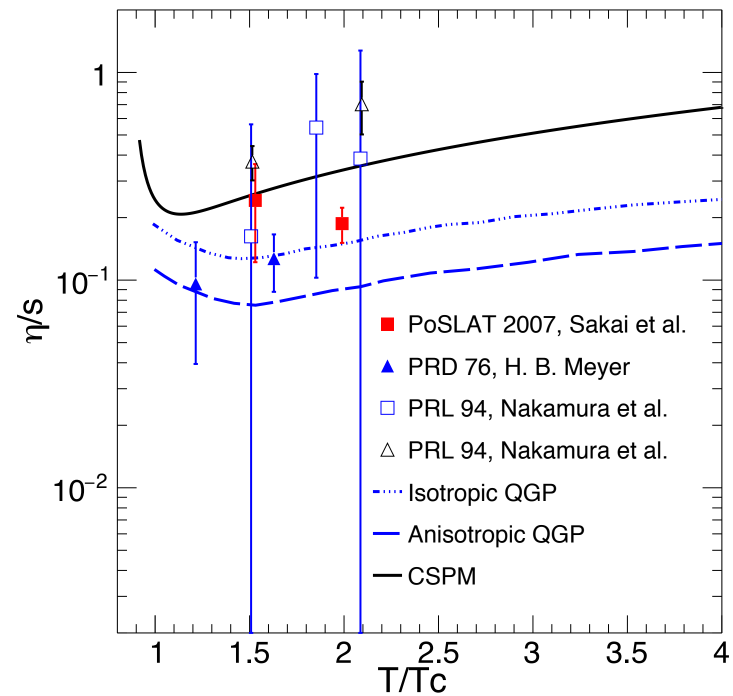
- In the framework of CSPM , the shear viscosity–to–entropy density ratio (η/s) is,

$$\eta/s \simeq \frac{TL}{5(1-e^{-\xi})}$$

Results

- The conductivity stays almost constant with increasing temperature in a fashion similar to that shown by BAMPS (Boltzmann approach to multiparton scattering) data.
- It matches the results obtained in BAMPS with the fixed strong coupling constant considering the elastic cross section only.



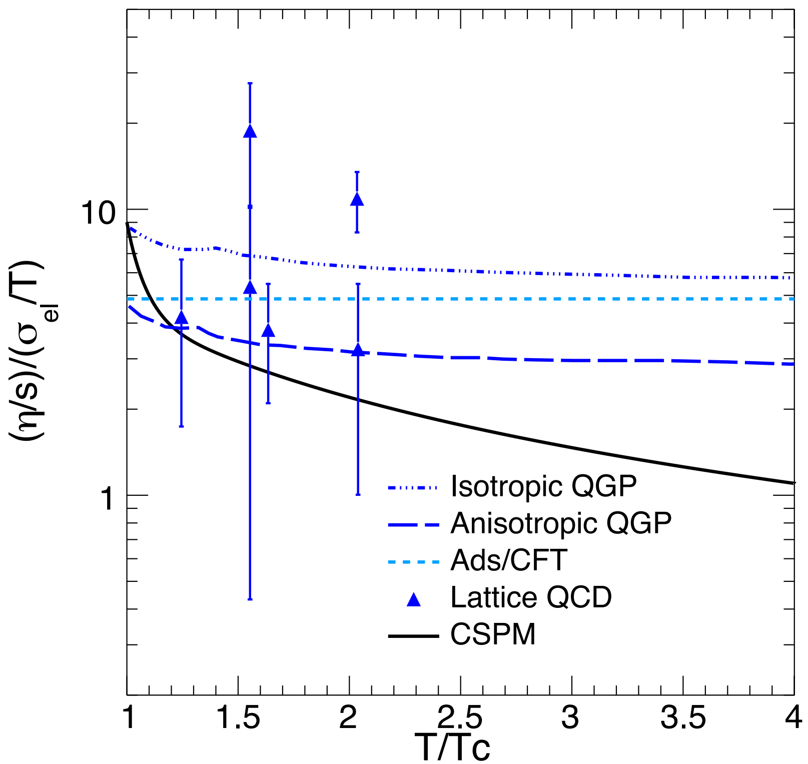


- In the CSPM, η/s first decreases, and after reaching a minimum value, it starts increasing with temperature. Thus, it forms a dip that occurs at T/Tc = 1. The quasiparticle model results show a similar behavior, but the dip does not occur at the critical temperature in this case.

P. Sahoo, S. K. Tiwari, R. Sahoo, Phys. Rev. D 98, 054005 (2018)

Results

- The η/s is affected by the gluon-gluon and quark- quark scatterings.
- σ_{el} is only affected by the quark- quark scatterings.



- A small value of η/s suggests large scattering rates , which can damp the conductivity.

P. Sahoo, S. K. Tiwari, R. Sahoo, Phys. Rev. D 98, 054005 (2018)

Summary

- The study of thermodynamical and transport properties like electrical conductivity and shear viscosity to entropy ratio of the QCD matter created at high energy heavy-ion collisions by using the clustering of color sources phenomenology has done.

- The minimum η/s is observed which envisages the formation of perfect fluid like matter created in high energy heavy-ion collision scenario.

- The normalized electrical conductivity (σ_{el}/T) estimated using the CSPM approach shows a very weak dependence on the temperature.

Thank you for your attention..