Out-of-equilibrium chiral magnetic effect at strong coupling[†]

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The chiral magnetic effect in relativistic heavy-ion collisions has been proposed as a signature of local parity violation in QCD above deconfinement phase transition[1)]. The manifestation of the chiral magnetic effect requires both a strong magnetic field and chiral imbalance in fundamental quarks. Despite continuous theoretical efforts in understanding the effect, many quantitative questions remain unanswered. One of them is the value of the chiral magnetic conductivity, which is complicated by the fact that the magnetic field produced by the spectators exists only at the early stage of the collisions, when quark-gluon plasma (QGP) is not yet thermalized. An accurate calculation of the chiral magnetic conductivity should be carried out for QGP in an out-of-equilibrium setting. In this work, we report on our attempt in this direction

We considered chirally imbalanced QGP undergoing thermalization. It can be modeled by a gravitationally collapsing shell in 5D Anti-de Sitter (AdS) space. The shell carries an axial charge density, described by an axial chemical potential μ_A. The end point of the gravitational collapse is the formation of the AdS-Reissner-Nordstrom (AdS-RN) black hole, which is dual to QGP with an axial charge density. The central quantity is the chiral magnetic conductivity in the thermalization process. It is defined for at finite frequencies as the response of the vector current to the external magnetic field

$$\vec{J}_{EM} = \sigma_\chi(\omega)\vec{B}(\omega). \tag{1}$$

This is to be evaluated at different times in the thermalization history. Note that (1) assumes the current response is much faster than the evolution of QGP toward equilibrium, which is not true in the near-equilibrium regime. We restricted our study to the far-from equilibrium regime. We obtained the chiral magnetic conductivity for different frequencies in Fig. 1. The end point QGP has a temperature $T = 300$ MeV and an axial chemical potential $\mu_A = 50$ MeV. We found that in general the chiral magnetic conductivity increases as QGP thermalizes, which is consistent with the expectation that more and more thermalized constituents are available in conducting the current. We also found that the magnitude of conductivity changes only slightly as the frequency of the magnetic field is varied, while increasing the frequency does results in longer delay in the response. We stress that the conventional conductivity has the opposite behavior.

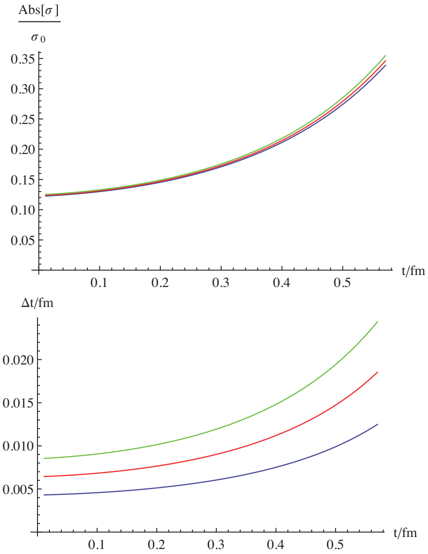

Fig. 1. The chiral magnetic conductivity as a function of thermalization history for frequencies $\omega = 200$ MeV(blue solid), $\omega = 300$ MeV(red dashed) and $\omega = 400$ MeV(green dotted). The left plot shows the magnitude normalized by chiral magnetic conductivity in equilibrium and the right plot shows the time delay of the response.

We also studied the chiral magnetic wave in the same thermalization model for QGP with vanishing axial charge density. The chiral magnetic wave rises from a coupled fluctuation of the axial and vector charges in the presence of a background magnetic field. In equilibrium, it has the dispersion $\omega = \mp v_\chi k$, with the wave velocity proportional to the magnetic field and the velocity changes sign when the chirality of the charge is reversed[2)]. We found that the dispersion relation is modified to

$$\omega = v_{out}k \mp \Delta\omega(k, B). \tag{2}$$

We see that the frequency splits into two terms: The first term is entirely of off-equilibrium origin: the wave velocity v_{out} vanishes as QGP thermalizes; It is also independent of the chirality of the charge. The second term depends on the chirality, and it is linear in both k and B. It is reminiscent of chiral magnetic wave velocity in equilibrium. This shows that the physical effect of the chiral magnetic wave may be enhanced owing to the out-of-equilibrium effect.

References

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[†] Condensed from the article in Phys. Rev. D **88**, 025030 (2013)

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