Gluon collective modes in anisotropic thermo-magnetic medium

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Introduction

Several studies on heavy-ion collisions suggest that the deconfined quark-gluon plasma(QGP) matter produced in the ultra-relativistic heavy ion collision experiments at RHIC and LHC is likely to possess substantial deviation from perfect local isotropic equilibrium. At early times after nuclear impact large pressure anisotropy is expected in the center of the fireball. Incorporating such large momentum space anisotropy, aHydro i.e, anisotropic hydrodynamics is developed. With certain classes of anisotropic momentum distributions, the non-equilibrium plasma properties can be described by studying the collective modes of the quasipartons in the framework of hard thermal loop perturbation theory [1]. Due to the presence of non-equilibrium momentum distributions in QGP medium, existence of kinetic instabilities is expected. The presence of such Chromo-Weibel instabilities can influence the thermalization and isotropization of the medium.

On the other hand, the production of strong magnetic fields [2] at early stages of the non-central heavy-ion collisions has triggered enormous research interest in the theoretical, phenomenological and experimental understanding of the strongly interacting matter under extreme conditions. We study the collective modes of gluon in an anisotropic thermal medium in presence of a constant background magnetic field using the hard-thermal loop (HTL) perturbation theory.

Formalism

The general structure of gluon self-energy in presence of two anisotropic directions and thermal medium can be written as a linear combination of the six basis tensors as

$$\begin{aligned}\Pi^{\mu\nu} &= \alpha A^{\mu\nu} + \beta B^{\mu\nu} + \gamma C^{\mu\nu} \\ &\quad + \delta D^{\mu\nu} + \sigma E^{\mu\nu} + \lambda F^{\mu\nu} \,. \end{aligned} \tag{1}$$

Using the Dyson-Schwinger equation, one can write the general structure of effective gluon propagator as

$$\begin{aligned}\mathcal{D}^{\mu\nu} &= -\frac{\beta\delta - (\beta+\delta)P^2 - \lambda^2 + P^4}{\Delta} A^{\mu\nu} \\ &- \frac{\delta\alpha - (\delta+\alpha)P^2 - \sigma^2 + P^4}{\Delta} B^{\mu\nu} \\ &- \frac{\gamma\left(P^2-\delta\right) + \sigma\lambda}{\Delta} C^{\mu\nu} \\ &- \frac{\alpha\beta - (\alpha+\beta)P^2 - \gamma^2 + P^4}{\Delta} D^{\mu\nu} \\ &- \frac{\sigma\left(P^2-\beta\right) + \lambda\gamma}{\Delta} E^{\mu\nu} \\ &- \frac{\lambda\left(P^2-\alpha\right) + \gamma\sigma}{\Delta} F^{\mu\nu} - \zeta\frac{P^\mu P^\nu}{P^4}, \end{aligned} \tag{2}$$

where the common denominator of the basis tensors, Δ is given by

$$\begin{aligned}\Delta &= P^6 - (\alpha+\beta+\delta)P^4 \\ &- (\gamma^2+\sigma^2+\lambda^2-\alpha\beta-\beta\delta-\delta\alpha)P^2 \\ &+ \alpha\lambda^2 + \beta\sigma^2 + \delta\gamma^2 - \alpha\beta\delta - 2\gamma\sigma\lambda \\ &= (P^2-\Omega_0)(P^2-\Omega_+)(P^2-\Omega_-), \end{aligned} \tag{3}$$

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Here, Ω_0 and $\Omega_\pm$ are three dispersive modes. The analytical expressions of the modes are presented in Ref. [3]. The six form factors $\alpha, \beta, \gamma, \delta, \sigma$ and λ can be calculated from one-loop gluon self-energy.

Results and Summary

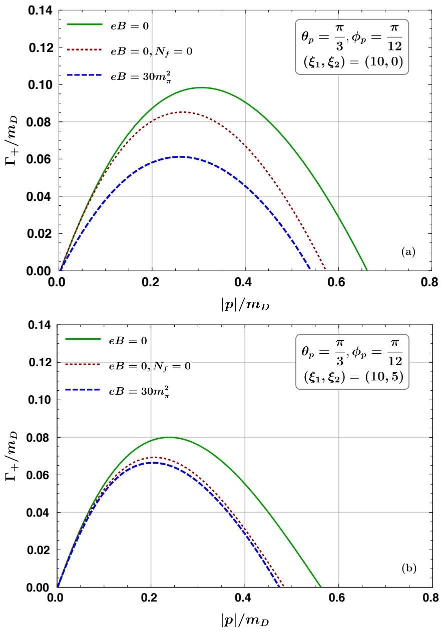

FIG. 1: The growth rate corresponding to Ω_+ mode is plotted for (a) $\xi = (10, 0)$ and (b) $\xi = (10, 5)$ at fixed angles $\theta_p = \pi/3$, $\phi_p = \pi/12$. The continuous and the dashed curves correspond to the magnetic field strength 0 and $30m_\pi^2$ respectively. The pure gluon result is also shown for comparison.

The collective modes of gluon in the presence of momentum space anisotropy along with a constant background magnetic field have been studied using the hard-thermal loop perturbation theory. The collective modes depend on the polar as well as on the azimuthal angels corresponding to the propagation direction. The retarded gluon polarization function is given as the sum of two contributions: one is coming from gluon and ghost loops in presence of anisotropic momentum distribution and the other one is coming from the quark loop in presence of magnetic field [4] i.e.

$$\Pi^{\mu\nu}_{ab}(p, eB, \xi, \Lambda_T) = \tilde{\Pi}^{\mu\nu}_{ab}(p, \xi_1, \xi_2, \Lambda_T) + \bar{\Pi}^{\mu\nu}_{ab}(p, eB, \xi_2, \Lambda_T)\ . \quad (4)$$

We obtain the one loop gluon self energy in presence of anisotropic thermo-magnetic medium within HTL approximation following the real-time Schwinger-Keldysh formalism.

In fig. 1, we plotted the unstable mode for Ω_+ for two cases. It can be observed that in both cases the amplitude of the growth rate significantly decreases in presence of the external magnetic field. It is also interesting to compare these modified growth rates with the pure gluon results. This is because, it provides information on the relative importance of the field dependent part compared to the field independent part of the self energy. For the spheroidal and ellipsoidal anisotropy without any magnetic background, there exists a critical value of the momentum beyond which the growth rate becomes negative and the instability ceases to exist. When the external magnetic field is turned on, we observe a significant decrease in the critical momentum providing a smaller momentum window for the positive growth rate. Here we note that no unstable gluon mode exists in an isotropic medium even in the presence of a background magnetic field. It is the momentum space anisotropy that gives rise to the instability. However, the external magnetic field has a significant influence on the growth rate of the unstable modes.

References

[1] S. Mrowczynski, A. Rebhan and M. Strickland, Phys. Rev. D **70**, 025004 (2004)

[2] D. E. Kharzeev, L. D. McLerran and H. J. Warringa, Nucl. Phys. A **803**, 227-253 (2008)

[3] R. Ghosh, B. Karmakar and A. Mukherjee, Phys. Rev. D **102**, no.11, 114002 (2020)

[4] B. Karmakar, R. Ghosh and A. Mukherjee, [arXiv:2204.09646 [hep-ph]].