

Chemical equilibration of QCD medium for photon v_2 puzzle

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Discovery of the quark-gluon plasma (QGP), a deconfined phase of QCD, at BNL Relativistic Heavy Ion Collider and CERN Large Hadron Collider is a milestone in hadron physics. The produced medium is considered to be strongly coupled because the momentum anisotropy in hadronic spectra is large enough to validate hydrodynamic description. This is quantified by elliptic flow v_2 defined as a Fourier expansion coefficient of the yield N:

$$\frac{dN}{d\phi} = \frac{N}{2\pi}[1 + 2\sum_{n=1} v_n \cos(\phi - \Psi_n)], \qquad (1)$$

where ϕ is the azimuthal angle in momentum space and Ψ_n is the n-th harmonic event plane. On the other hand, direct photon v_2 is found to be a few times larger than hydrodynamic predictions,[1,2] which is recognized as the "photon v_2 puzzle." Of direct photons, thermal photons from the QGP medium are the dominant source of anisotropy because prompt photons from initial hard processes do not have it intrinsically.

In this work, I have considered the effects of chemical equilibration in the QGP on thermal photon v_2.[3] A heavy-ion system before the collision is described as the color glass condensate, a state of saturated gluons. Several early equilibration models indicate that chemical equilibration is slower than thermalization.[4] This implies that the quark number at the onset of hydrodynamic evolution is smaller than that under equilibrium. Since photons are coupled to quarks, late chemical equilibration suppresses the emission of thermal photons in the early stages where flow anisotropy is still small. Consequently, thermal photon v_2 can become effectively large owing to the contribution from later times.

I have developed a new (2+1)-dimensional ideal hydrodynamic model and coupled it to the rate equations for the parton number densities. The number changing processes are (a) $g \leftrightarrow gg$, (b) $g \leftrightarrow q\bar{q}$, and (c) $q(\bar{q}) \leftrightarrow gq(g\bar{q})$. Here, the vanishing net baryon number limit is considered. The relaxation equations are:

$$\partial_\mu N_q^\mu = 2r_b n_g - 2r_b \frac{n_g^{\mathrm{eq}}}{(n_q^{\mathrm{eq}})^2} n_q^2, \qquad (2)$$

$$\partial_\mu N_g^\mu = (r_a - r_b) n_g - r_a \frac{1}{n_g^{\mathrm{eq}}} n_g^2 + r_b \frac{n_g^{\mathrm{eq}}}{(n_q^{\mathrm{eq}})^2} n_q^2 + r_c n_q - r_c \frac{1}{n_g^{\mathrm{eq}}} n_q n_g, \qquad (3)$$

where r_a, r_b, and r_c are the reaction rates. Since pair production is the only quark numbe-changing process, chemical equilibration time would be given by $\tau_{\mathrm{chem}} = 1/r_b$. Here, the rates are parametrized as $r_i = c_i T$. The equation of state is a hyperbolic interpolation of those for hadron and parton gases with $N_f = 2$. The thermal photon emission rate is also derived from those for the hadron and QGP phases.

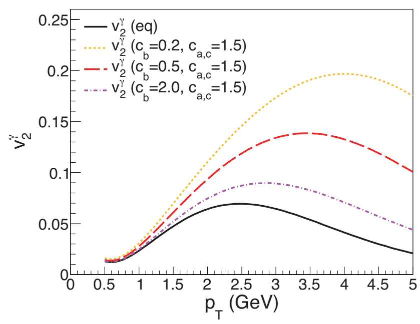

Fig. 1. Thermal photon v_2 with different quark chemical equilibration rates.

Figure 1 shows the elliptic flow of thermal photons for Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV with the impact parameter $b = 7$ fm. The chemical reaction parameters are chosen as $c_b = 0.2, 0.5$, and 2.0, where $c_{a,c} = 1.5$. Thermal photon v_2 can be visibly enhanced by late quark chemical equilibration. For the suggested chemical equilibration time $\tau_{\mathrm{chem}} = 2$ fm,[4] $c_b = 0.5$ follows from $T \sim 0.2$ GeV. The dependences on the gluon number-changing processes characterized with r_a and r_c are found to be small as expected. The particle spectrum of thermal photons is not affected much by chemical non-equilibrium with the current parameter settings. This implies that late quark chemical equilibration is important to explain the photon v_2 problem. It should be noted that the mechanism can also be an explanation to the large photon v_3 recently observed in the experiments.

Future prospects include the introduction of a dynamical equation of state, improved initial conditions, and chemical equilibration rates. Effects of viscosities would also be important in quantitative discussion because thermal photons are sensitive to early-time fluid dynamics where off-equilibrium corrections are large because photons can pass through the QCD medium.

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