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The extraordinary glow

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Abstract

In this contribution I discuss some recent progress in understanding the evolution of the pre-thermal quark–gluon matter, known as the glasma, during the early stage in heavy ion collisions, and the implication for early time photon and dilepton emissions.

Keywords: Heavy ion collisions; Quark–gluon plasma; Glasma; Electromagnetic probes

1. Introduction

This is a contribution to the memorial volume as proceedings for the conference "45 Years of Nuclear Theory at Stony Brook: A Tribute to Gerald E. Brown". I came to study for PhD at Stony Brook in 2004 and two years later officially became a student in the Nuclear Theory Group. Unlike many other contributors in this volume, I was neither a student/postdoc nor a collaborator of Gerry — at the time Edward Shuryak was my advisor. But like all the other contributors, I benefited so much from Gerry through the numerous physics discussions and personal interactions. The great care, the generous help, and the extreme kindness that he bestowed upon young people like me, was "the extraordinary glow" that fostered the growth of generations of nuclear theorists, and that I was really lucky to enjoy and appreciate.

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The last physics discussions I had with Gerry were about the photon and dilepton measurements from PHENIX Collaboration at Relativistic Heavy Ion Collider (RHIC). That was during my last few months of PhD and I was about to leave for my first postdoc position at LBNL, for which Gerry gave me a great deal of help in my application. In short, the PHENIX measurements show large excess of low-to-intermediate mass dileptons in AuAu collisions, beyond contributions from all usual emission sources considered at the time [1–3]. Gerry had always been very interested in the behavior of meson masses in the temperature regime $120 \sim 170$ MeV particularly related to chiral symmetry restoration. He had the idea that such excessive dileptons may come from a "sticky-pion" picture, in which very light pions merge in specific way into similarly light rho mesons which then decay into soft dileptons. We spent quite many hours discussing such processes and he encouraged me to talk with Volker Koch further when I arrived at LBNL and to work together on this problem. That did not go very far, particularly after the very unfortunate health situation of Gerry that occurred just few months after my graduation. A few years later, I came back to this problem about "the extraordinary glow" in heavy ion collisions, from a quite different angle [4]. While the idea of Gerry pertains to the emission from the very late stage (i.e. the hadronic gas) of evolution, the more recent development that I will discuss in the rest of this article has the emission origin from the very early stage (i.e. the pre-thermal glasma) of evolution. Gerry and I could have enjoyed a delightful discussion on this if he were still with us.

2. The overpopulated glasma

Thermalization of the quark–gluon plasma is one of the most challenging problems in current heavy ion physics [5–9]. Starting with two colliding nuclei in a form of color glass condensate, the system shortly after the initial impact becomes a very dense, far-from-equilibrium system of gluons called the "glasma". The glasma has high gluon occupation $1/\alpha_s$ up to the saturation scale Q_s of few GeV (implying a viable weak coupling approach). Extensive phenomenological studies suggest that the evolution of this glasma stage toward a hydrodynamically expanding quark–gluon plasma occurs at a time of the order of $1\text{fermi}/c$. Exactly how this happens remains a big puzzle.

Since the initial scale Q_s in the glasma is large and thus the coupling is weak, the kinetic theory seems to be a natural and plausible framework to investigate the detailed evolution of the phase space distribution in the dense gluon system starting from the time scale $\sim 1/Q_s$. Such efforts were initiated long ago [10–18], with many highly interesting developments in the past few years: see e.g. review and references in [5,6]. An apparent tension in such approaches exists in that in a naive counting the scattering rate (of leading elastic processes) $\sim\alpha_s^2$ may not be able to bring the system back to thermalization quickly enough. A number of past kinetic works suggest that the inelastic processes may play more significant role as compared with the elastic ones in speeding up the thermalization process, especially in populating the very soft momentum region. This may be true in the dilute regime (close to the Boltzmann limit), however may not be the accurate picture when the system under consideration is in the *highly overpopulated regime* with $f \sim 1/\alpha_s$. As shown in a number of recent kinetic studies [19–24], the elastic scatterings with highly overpopulated initial conditions can lead to order $\sim\alpha_s^0$ evolution and develop strong infrared cascade with the Bose enhancement, and in fact may even induce a dynamical Bose–Einstein Condensation. (In passing let us mention that there have also been lots of developments in understanding the evolution of overpopulated glasma with different approaches, see e.g. [25–28].) In this section let us briefly discuss some of these nontrivial features of the glasma as a basis for our discussions of its electromagnetic emissions in the next section.