PROCEEDINGS OF SCIENCE

Neutrino quantum kinetics in SN and binary mergers

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In hot and dense matter-environments such as the inner regions of core-collapse supernova (CCSN) and the remnant of binary neutron star mergers (BNSM), a great number of neutrinos are radiated. In such dense neutrino environments, neutrinos can interact among themselves, which has a potential to trigger various types of flavor conversion instabilities. This requires a quantum kinetic treatment in neutrino transport, which could be a game changer for CCSN and BNSM theories. In this conference, I introduce the current status of numerical modeling of qnatum kinetic neutrino transport in CCSN and BNSM environments and discuss future perspectives.

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1. Introduction

Neutrinos are known to play important roles on fluid dynamics and nucleosynthesis in high-eneargy astrophysical phenomena such as core-collapse supernova (CCSN) and binary neutron star merger (BNSM). They are produced via various weak interaction channels, and then propagate in dense matter where other particles (charged leptons, baryons, and photons) are trapped in medium. The transport of energy and lepton is, hence, dominated by neutrinos in such environments.

There are at least three different flavor states in neutrinos. In CCSN and BNSM environments, all flavors are produced via different weak processes and their opacities also depend on neutrino flavors, which results in flavor-dependent neutrino radiation field. As another crucial property of neutrinos, their mass- and flavor eigenstates are misalighnment, which induce neutrino oscillations. On the other hand, it has been recognized that neutrino oscillations are suppressed in the inner regions of CCSN and BNSM. This is because neutrino matter interactions (or forward-scatterings with matter) in high density environments effectively hold mass eigenstates close to flavor ones. For this reason, the neutrino transport in CCSN and BNSM has been modeled by solving Boltzmann equation.

One thing we do notice here is that the above argument is incomplete, since it neglects effects by neutrinos self-interactions. In fact, they can trigger collective neutrino oscillations. Recent inspections of neutrino radiation fields in CCSN and BNSM obtained by sophisticated numerical simulations have commonly suggested that fast flavor conversions (FFC) and collisional flavor instability (CFI) ubiquitously occur [1–4]. In this conference, we introduce the current status of the field, and then present some key findings based on our quantum kinetic neutrino transport simulations for FFC.

2. Method

In most of our simulations, we employed GRQKNT code, which has capabilities of solving general relativistic quantum kinetic equation with taking into account essential sets of neutrino-matter interactions. The code design and detailed tests are summarized in [5].

3. Result

One of the major impacts of flavor conversions on CCSN dynamics is that the neutrino cooling and heating could be substantially changed. According to the detailed quantum kinetic neutrino transport in [6, 7], the neutrino cooling in the optically thick region is enhanced by $\sim 30\%$, whereas the heating in the gain region is reduced by $\sim 40\%$. In [8], we also demonstrated that neutrinos undergo flavor swap (which corresponds to the complete exchange of flavors between electron-type to others) in BNSM. Our result sugges that flavor conversions can radically change the radiation field in both CCSN and BNSM environments, and that these non-linear features are strongly depending on global geometry of fluid background.

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4. Summary

In this conference, we present some recent results of our quantum kinetic simulations in CCSN and BNSM environments. According to our studies, non-linear evolutions of collective neutrino oscillations are depending on global geometries of neutrino radiation field. In the current status, there have been little studied on the impact of global advections of neutrinos on flavor conversions, but this important issue should be addressed in future work. Indeed, the impacts of neutrino flavor conversions on CCSN and BNSM can be revealed only by such global simulations.

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