Comparison of Radiative Hydrodynamics and Post-processed Hydrodynamics in Cosmological Simulation of the Local Universe

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1 Introduction

Understanding the Epoch of Reionization (EoR) that is thought to have occurred $z \sim 5 - 11$ is very crucial in understanding the galaxy formation and the evolution of the universe. In the era of recently launched James Webb Space Telescope (JWST), more distant galaxies, possibly the first galaxies, lying in the earlier universe will be captured by the observation specialists. Therefore to interpret the observation results and assess the impact of the young galaxies on the cosmic environment, efforts to simulate EoR within our current understood galaxy formation theory and cosmology should proceed as well.

There are several ways to simulate the high-redshift universe but we will focus on two methods: coupled radiative hydrodynamics (RHD) [1–3] and post-processing on pure hydrodynamics [4, 5]. One of the important physical quantity that is highly important in EoR and typically analyzed in simulations is ionizing photon escape fraction ($f_{\rm esc}$) from young galaxies. It is well-known that bursty star formation and energetic stellar feedback in young galaxies can make interstellar medium (ISM) in the galaxies ionized rapidly thus leading to the higher $f_{\rm esc}$. Since the process is governed by highly chaotic and turbulent ISM, the numerical resolution that can resolve the inner structure of galaxies is important. Thus, post-processing on pure hydrodynamics simulation has an advantage compared to RHD simulation, which clearly needs more computation resources. However, in the former method, we always adopt some kind of assumptions, such as a redshift-dependent uniform meta-galactic UV background. The problem is, this is not exactly how the gas and ionizing photons interacts. In EoR, ionizing photons emitted from galaxies are thought to produce "patchy reionization" of the universe, which means that ionization of gas is totally non-uniform and affected by nearby photon-emitting galaxies. To understand EoR in a better way, some cosmological simulations were dedicated to couple radiative process and gas hydrodynamics and could give us better insights on EoR.

The only problem of fully-coupled RHD is that those simulations are very computationally expensive. In this project, we will compare ionizing photon escape fraction from similar halos in comparable environment in fully-coupled RHD simulations using N-body RHD code RAMSES-RT and post-processed pure hydrodynamics simulations using N-body hydrodynamics code RAMSES.

2 Computation Time

For RHD simulation, for a test, we ran an $8h^{-1}$ Mpc, unigrid (512^3 cells) simulation (still running because of the slow speed) starting at $z = 150$, with a reduced light speed approximation ($c_{\rm apprx} = 0.1c$) and it took 48 hours to proceed $\sim 20\%$ of the whole progress down to $z = 3$ with 1024 cores in 64 `skx` node. Because of the memory demands, we couldn't use all the cores in the nodes. This means that $3072 \times 5 \sim 15,000$ SUs are needed to complete the whole simulation. On the other hand, to run pure hydrodynamics simulation, according to the attached performance document, 1.5 hour is need to complete the same simulation without radiative transfer with 512 cores in 64 `KNL` nodes. This means $\sim$ 100 SUs are need for hydrodynamics simulation. We also propose to run simulations with box size of $16h^{-1}$ Mpc. According to the performance document, if we increase box size by a factor of two, computation time need will be increased by 16 times. This means that we need 240,000 SUs in 64 nodes, which means 3750 Node-hours or 156 Node-days are needed.

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