Mergers of Accreting Stellar-mass Black Holes

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Recent observations have revealed the existence of supermassive black holes (SMBHs) with masses $\gtrsim 10^9 M_\odot$ at redshifts higher than 6 [1]. However, the formation history of these SMBHs is not still revealed. There are two major competitive scenarios for the growth of SMBHs: one is the mass accretion, and the other is the merger of BHs (or stars). As for the mass accretion, the constraints from observed SMBHs at high redshifts have been argued. Possible building blocks of SMBHs are the remnants of first stars. First stars of several tens $M_\odot$ can leave black holes (BHs) of few tens $M_\odot$ after supernova explosion. If recently discovered high-redshift SMBHs grow via mass accretion from such stellar-mass BHs, the accretion rate is required to be higher than the Eddington accretion rate. However, the continuous accretion is unlikely to be sustained due to feedback, and thus the average mass accretion rates should be lower than the Eddington rate [2]. Then, if the BHs grow via BH mergers by a few orders of magnitude, the high-redshift SMBHs can be formed from stellar-mass BHs.

Then we focus on the promotion of BH mergers in abundant gas at high-redshift epochs. Recent radiation hydrodynamic simulations on the formation of first stars show that multiple massive stars form in a primordial gas cloud of $\sim 10^4$–$10^5 M_\odot$ with the density of around $10^7\,\mathrm{cm}^{-3}$ and the extension of ~0.01 pc, where the gas fraction is 99 %. According to the mass function of first stars, multiple BHs of several tens $M_\odot$ may be born as remnants of supernovae, in such a primordial could [3]. In this circumstance, high mass-accretion rates onto BHs are expected. On the other hand, plenty of gas can exert dynamical friction on moving BHs. Recently, we have explored the early merger of BHs through the gas dynamical friction, and have shown that the merger time of multiple BHs merger in the gas number density of $n_{\mathrm{gas}} \gtrsim 10^6\,\mathrm{cm}^{-3}$ is $\sim 10^7$ yr, which is shorter than the Eddington timescale [4]. However, this study [4] did not consider the effect of the mass accretion onto BHs. Thus, in the competition between the mass accretion and the merger, which mechanism dominates the growth of massive BHs is not clear. Then, we present post-Newtonian *N*-body simulations on mergers of accreting stellar-mass black holes (BHs), where such general relativistic effects as the pericenter shift and gravitational wave (GW) emission are taken into consideration. The attention is concentrated on the effects of the dynamical friction and the Hoyle-Lyttleton mass accretion by ambient gas. As a result, we show that mergers of accreting stellar-mass BHs are classified into four types: a gas drag-driven, an interplay-driven, a three body-driven, or an accretion-driven merger. Using the simulation results for a wide range of parameters, we derive a critical accretion rate ($\dot{m}_c$), below which the BH growth is promoted faster by mergers (Figure 1). We find that BH mergers proceed before significant mass accretion, even if the accretion rate is ~10 Eddington accretion rate, and then all BHs can merge into one heavy BH [5].

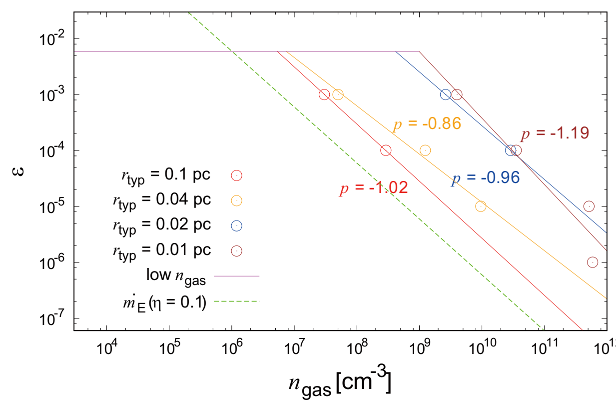

Figure 1: The critical accretion efficiency ($\epsilon_c = \dot{m}_c / \dot{m}_{\mathrm{HL}}$) as a function of ambient gas density n_{gas}. Red, orange, blue, and brown plots represent the critical condition in high-density regions for r_{typ} = 0.1, 0.04, 0.02, and 0.01 pc, respectively. Red, orange, blue, and brown lines represent the curves fitted by $n_{\mathrm{gas,c}} = a\epsilon^p$ for r_{typ} = 0.1, 0.04, 0.02, and 0.01 pc. Pink line represents the critical condition in low-density regions. The green dashed line represents the Eddington accretion rate $\dot{m}_{\mathrm{E}}$ (η = 0.1), where η is the radiative energy conversion efficiency.

References

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