Early Cosmic Merger of Multiple Black Holes

TAGAWA, Hiromichi (University of Tokyo)
UMEMURA, Masayuki (University of Tsukuba)
GOUDA, Naoteru (University of Tokyo/NAOJ)
YANO, Taihei (NAOJ)
YAMAI, Yuki (Mitsubishi Space Software co., Ltd.)

At redshifts higher than six quasars are found that possess SMBHs with the mass higher than $10^9\,M_\odot$ [1]. The formation history of these SMBHs is among the most significant unsolved issues in astrophysics. For SMBHs to grow from such first star remnants through mass accretion at $z > 6$, a super-Eddington accretion rate is requisite. However, the continuous accretion is unlikely to be sustained due to feedbacks, and thus the average mass accretion rates should be lower than the Eddington rate [2]. Another possible pathway of SMBH formation is the merger of BHs. If the merger of multiple black holes precedes the growth via gas accretion, the merged BH can be a seed of a supermassive black hole.

Recent radiation hydrodynamic simulations on the formation of first stars show that several or more stars form in a primordial gas cloud with the density of around $10^7\,\mathrm{cm}^{-3}$ and the extension of 1000 AU, where the gas fraction is 99 % [3]. In this circumstance, BH remnants of first stars are most likely subject to the dynamical friction by abundant gas. The gas dynamical friction has been considered as a mechanism that prompts the BH merger. Hitherto, the merger processes by the gas dynamical friction have been investigated in the case of two massive BHs (e.g. Escala 2004, Escala 2005). In our study, we explore the merger of multiple BHs, supposing a first-generation object of $\sim 10^5$–$10^6\,M_\odot$ or a gas-rich primordial galaxy of $\sim 10^8$–$10^9\,M_\odot$.

The simulations incorporate such general relativistic effects as the pericentre shift and gravitational wave emission.

As a result, we find that multiple BHs are able to merge into one BH within 100 Myr in a wide range of parameters. In the case of $M_{\rm BH} = 30\,M_\odot$, if multiple BHs are embedded in the gas density with $n_{\rm gas} = 5\times10^6$ to $10^8\,\mathrm{cm}^{-3}$, then all the BHs can merge together over six orders of BH density as $\rho_{\rm BH} = 72-7.2\times10^7\,M_\odot\,\mathrm{pc}^{-3}$. The merger mechanism is revealed to be categorized into three types: gas drag-driven merger (type A), three body-driven merger (type C), and interplay-driven merger (type B). We find the relation between the merger mechanism and the ratio of the gas mass within the initial BH orbit ($M_{\rm gas}$) to the total BH mass ($\sum M_{\rm BH}$). Type A merger occurs if $M_{\rm gas} \gtrsim 10^5 \sum M_{\rm BH}$, type B if $M_{\rm gas} \lesssim 10^5 \sum M_{\rm BH}$, and type C if $M_{\rm gas} \ll 10^5 \sum M_{\rm BH}$. Supposing the gas and BH density based on the recent numerical simulations on first stars, all the BH remnants from first stars are likely to merge into one BH through the type B or C mechanism. The present results imply that the BH merger may contribute significantly to the formation of supermassive BHs at high redshift epochs [4].

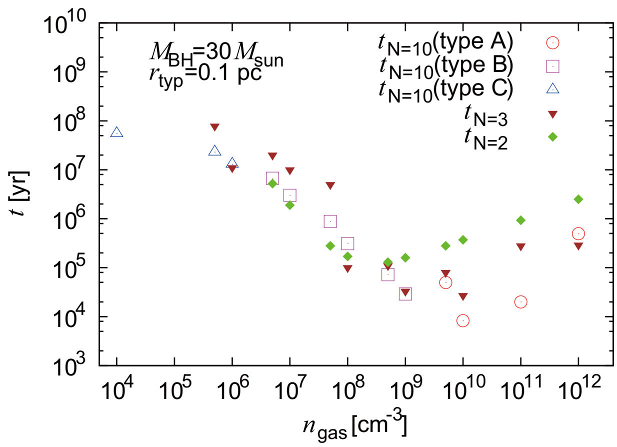

Figure 1: Merger time in ten-BH systems ($t_{N=10}$) as a function of gas number density $n_{\rm gas}$. Red, pink, and blue open symbols represent the results of the type A, B, and C mergers, respectively. Green- and brown-filled symbols are the results of two-BH ($t_{N=2}$) and three-BH ($t_{N=3}$) systems, respectively.

References

[1] Fan, X.: 2001, *AJ*, **122**, 2833.
[2] Milosavljevic, M., Couch, S. M., Bromm, V.: 2009, *ApJ*, **696**, 146.
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[4] Tagawa, H., et al.: 2015, *MNRAS*, **451**, 2174.