論文の内容の要旨

The merger processes of multiple stellar-mass black holes
(多重恒星質量ブラックホールの合体過程)

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Exploring the merger processes of stellar-mass black holes (BHs) is important since the mergers of stellar-mass BHs are related to the various unsolved problems such as formation processes of supermassive BHs (SMBH), an evolutional channel of the gravitational wave (GW) event, GW150914, and the origin of r-process elements. So far, the merger of stellar-mass BHs has been thought to result from the evolution of binary stars. In our study, we newly propose the merger processes evolved from a multiple of non-binary isolated BHs under gas rich environments.

In this thesis, we first explore the merger processes of multiple BHs under gas rich environments. For the purpose, we perform post-Newtonian N-body simulations, incorporating the effects of the gas dynamical friction, gas accretion, and GW emission. The attention is concentrated on the effects of the dynamical friction and the Hoyle-Lyttleton mass accretion by ambient gas. Our simulations solve the merger of more than three BHs with effects of gas for the first time. Such merger processes are important because a third BH, which decays due to the gas dynamical friction, effectively transports the angular momentum of binary BHs by the three-body interaction. As a result, our simulations suggest that multiple BHs are able to merge into one BH within 100 Myr in a wide range of BH number density. We also show that mergers of accreting stellar-mass BHs are classified into four types: a gas drag-driven merger (type A), an interplay-driven merger (type B), a three body-driven (type C), or an accretion-driven merger (type D). We find the relation between the merger mechanism and the gas density ($n_{\rm gas}$), the BH density ($\rho_{\rm BH}$), and the initial typical extention of BH spatial distribution ($r_{\rm typ}$). Type A or B merger occurs if $n_{\rm gas}\rho_{\rm BH}^{-1}r_{\rm typ}^{-1}$ is higher or lower than 8×10^{4} cm^{-3}pc$^{2}M_{\odot}$, respectively. Furthermore, we derive a critical accretion rate ($\dot{m}_{\rm c}$), below which the BH growth is promoted faster by mergers. Also, it is found that the effect of the recoil by the GW emission can reduce $\dot{m}_{\rm c}$ especially in gas number density higher than 10^{8} cm^{-3}, and enhance the escape probability of merged BHs.

Furthermore, we consider an evolutional channel of GW event, GW150914. Recently, the Laser Interferometer Gravitational-Wave Observatory (LIGO) has detected the GW event, GW150914, as a result of the merger of a $\sim 30\ M_{\odot}$ BH pair. So far, the merger of stellar-mass BHs has been thought to result from the evolution of binary stars. Here, we propose a novel path of the merger stemming from non-binary isolated stars. In our studies, we have found that multiple non-binary stellar-mass BHs whose separations are larger than 1000 AU can merge with each other under gas-rich environments through the gas dynamical friction and three-body interaction. In this case, a considerable amount of gas can accrete onto BHs before the merger, that is, the initial mass of BHs can be lower than 30 $M_{\odot}$. Based on our simulations, we find that the BH merger in GW150914 can be accounted for by the merger in galactic nuclear regions or dense interstellar cloud cores if the initial BH mass is higher than 25 $M_{\odot}$. Furthermore, we roughly estimate event rates to be $\sim$1 yr^{-1} in galactic nuclear regions and $\sim$7 yr^{-1} in dense interstellar cloud cores, and find that this estimated event rate is almost consistent with the event rate implied from hitherto detected GW events.

Next, we apply the merger processes to the several issues. First, we study the origin of r-process elements. Recently, it has been argued that r-process elements in galaxies primarily originate from the mergers of double neutron stars (NSs) and BH-NS. However, it has been pointed out that the estimated merger timescale (0.1-1 Gyr) is much longer than the timescale inferred from the abundance of r-process elements of metal poor stars in the Galactic halo (1-10 Myr). To solve this problem, we propose the rapid merger processes in gas-rich first-generation objects in a high redshift epoch. To explore the possibility of mergers in a system composed of multiple NSs as well as BHs, we perform post Newtonian N-body simulations. As a result, we find that NS-NS or NS-BH can merge within 10 Myr in first-generation objects. These results imply that the mergers in early cosmic epochs may reconcile the conflict on the timescale of NS mergers.

Also, we roughly estimate the event rates of short gamma-ray bursts (GRBs) by the NS-NS mergers evolved from non-binary stars. As a result, the NS-NS merger rates are ~0.6 yr^{-1} Gpc^{-3} in galactic nuclear regions and ~2 yr^{-1} Gpc^{-3} in dense interstellar cloud cores. We find that the non-binary star merger is likely to be a minor path of short GRBs.

Finally, to consider the formation processes of SMBHs at z~6, we discuss the possibility of the efficient growth of BHs via BH-BH mergers at high-redshift epochs. As a result, we suppose that the center regions of primordial galaxies can provide promising environments for the efficient growth of BHs via BH-BH mergers.