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Mergers of Stellar Mass Binary Black Holes in Disks around Supermassive Black Holes as LIGO Sources

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LIGO/Virgo recently discovered a binary black hole merger event GW190521 – an 85 solar mass and a 66 solar mass black hole (BH) coalescing to a 142 solar mass BH – the heaviest binary black hole (BBH) merger to date. This presents a challenge to the conventional models where individual BHs were thought to be < 50 solar masses. Adding to its intrigue, a possible electromagnetic (EM) counterpart to GW190521 was discovered within its error box (though the statistical significance of such an event is under debate). These discoveries heighten the need to understand the formation processes of "heavyweight" BBHs. One intriguing scenario for explaining these systems is to postulate the existence of stellar-mass black holes in disks around supermassive black holes at the centers of massive galaxies (often called AGNs). BHs embedded inside AGN disks can become "heavyweight" (above 50 solar masses) due to either accretion or mergers. Furthermore, when/if they form binaries, they could lead to GW events as observed by LIGO/Virgo.

We will present recent progress in several areas surrounding this scenario. The first is how BBHs will form, in which we find that the repeated collisions among the disks surrounding individual BHs play a significant role in dissipating the orbital energy and angular momentum. This indicates that the binary formation process could be quite robust in AGN disks. The second is to understand the orbital evolution of these binaries. We find that the flow around the binary forms a hierarchical structure with multiple disks and spirals in 3D. Different regions exert different torques to the binary orbit, and we examine the processes that will determine whether the binary will continue to merge or expand. Extensive high-resolution 3D simulations are critical in understanding these systems in detail. The third is how accretion and feedback within the Bondi sphere of the BH can be studied using general relativistic (GR)-MHD simulations. We find that the jets present strong feedback process, altering the flow structure around the BBH.

Taking them together, they provide the essential ingredients for understanding the plasma processes that lead to the possible accompanying electromagnetic emissions from gravitational wave (GW) events. In addition, their impact on AGN disks will be discussed as well. Implications for the ongoing LIGO/Virgo observations will be discussed as well.