Modeling of Gravitational Wave signals emitted from binary systems containing accretion disk

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Abstract

The binary systems of compact objects (neutron star, black hole, white dwarf) are one of the most important class of sources of gravitational wave (GW). By analyzing the GW waveform emitted from them one could check various predictions of general relativity both in the weak and strong field limit (Amaro-Seoane et al. and references therein). With the proposed launch of the space based GW detector LISA extreme and intermediate mass ratio inspirals (EMRI/IMRI), in which a stellar mass compact object ($10 - 10^3 M_\odot$) orbits a central super-massive black hole ($10^5 - 10^8 M_\odot$), have drawn the special attention of scientific community because of their detectability by LISA. Extreme or Intermediate mass ratio binary systems (E/IMRI) are believed to be present at the centre of the galaxies. For such systems, since the central black hole is extremely massive than its orbiting companion, the companion essentially behaves as a test particle following geodesic of the space-time given solely by the central black hole. Thus, observing the emitted GW from such systems one would be able to trace the trajectory of the orbiting object, from which a map of the space time can be obtained and therefore, test of general theory of relativity(GTR) can be done even in the very strong field regime. Detecting GW signals coming from distant sources is a formidable task as they have very small signal to noise ratio. Matched filtering technique, which basically cross correlates the incoming gravitational-wave signal with a bank of theoretically produced templates representing the expected signal as a function of the parameters of the source, is used for this purpose. It is therefore, extremely important to generate the theoretical wave form accurately, which in turn requires an exact modeling of the dynamics of the companion. Real E/IMRI systems are most likely to have massive accretion disks that may be as massive as the primary supermassive black hole. Therefore, in contrast to its ideal model, the accretion disk is a third crucial part of the actual E/IMRI system. This disk can exert non negligible hydrodynamic drag on the compact objects rotating around the central black hole. Hence, the gravitational wave (GW) signal emitted from an E/IMRI may be modified due to the modified motion of orbiting companion by the influence of hydrodynamic drag of the disk. The purpose of this dissertation is to predict the characteristic signature provided by the accretion disks encircling the center supermassive black hole of an E/IMRI on the emitted gravitational wave signal. As low-frequency (milli-hertz) GW astronomy develops, we expect to soon detect signals from merging SMBH systems. Understanding how an accretion disk affects an inspiralling SMBH binary is the main goal of this research, with the underlying aim of applying this information to interpret and support future GW detections. We study the influence of these disks on the emitted GW profile using a semi-relativistic formalism in the Kerr background. There are several potential accretion disk model and transonic solutions is one of them. We consider the transonic flow to describe the accretion flows around the active galactic nuclei(AGN). The influence of the disks could be identified through the difference in the infall time or from the acquired phase shift due to an extra disk-torque on the companion. Without incorporating such effects leads to error in parameter estimations such as masses of the companions, chirp mass, and more importantly the emitted GW strains amplitude. We compute the signal-to-noise ratio (SNR) of the detectability of these modifications and found that these changes are detectable through the last few years of observation by LISA (in some cases as small as six months) for EMRIs residing within redshift $z = 1$ from the detector and for the accretion rate of the primary black hole of the order of $\dot{M} = 0.01\dot{M}_E - 1\dot{M}_E$. The emitted GW varies depending on the initial systems orbital parameters and the accretion flow variables. We conduct an accurate investigation, by fixing the disk attributes and by altering the orbital parameters, mass ratio of the EMRI and spin of SMB to obtain the best-fitted optimal orbital parameters to enhance the detection ability of the accretion disk effect from the observed gravitational wave(GW) signal. We also check for the sensitivity of the detection of emitted GW to the chosen hydrodynamic model by varying the disk parameters, accretion rate and duration of observation of E/IMRIs, and find that in comparison with other disk models, transonic solution offers relatively better observable signatures in detecting the gas-riched E/IMRI's within the LISA band. Such observations of GW will help one to probe the nature of the accretion flow and verify various paradigms of accretion physics.

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