Abstract

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Doctor of Philosophy

Investigation of Black Hole Populations in Dense Stellar Systems using MOCCA code for Star Cluster Simulations

by
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In this thesis, we investigate black hole (BH) populations in dense star clusters using about 2000 star cluster models that were simulated with the MOCCA code for star cluster simulation as part of the MOCCA-SURVEY I Database project. Dynamical processes in dense stellar systems like globular clusters (GCs) can significantly influence the population of BHs that originate in these systems. Up to thousands of BHs can form in a GC within a few million years from the evolution of massive stars. Consequent evolution of BH populations is strongly determined by the initial GC parameters that govern its evolution.

We present in this thesis two studies on merging stellar mass binary BHs that originate from GCs. These BHs merge due to the emission of gravitational waves and can be detected by ground based gravitational wave detectors like aLIGO. We show that GCs are efficient factories for producing such binary BHs and the merger rates originating from GC is at least 5 $\mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$ and can be as high as 20 to 30 $\mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$. We also show that highly eccentric BH mergers can occur during strong interactions involving three BHs and the contribution of such mergers can be large when we consider post-Newtonian terms when computing these strong interactions.

Another paper presented in this thesis, deals with the formation of intermediate mass BHs in the dense stellar environment of a GC. We show that IMBHs may form in initially dense GCs that lose a significant amount of their mass over a Hubble time. At present times such GCs would appear to be low mass and dim but their kinematic properties could reveal the presence of an IMBH with a mass of at least a few thousand solar masses. We identify the Galactic GC NGC 6535 as a possible dark star cluster with an IMBH.

We have also included a paper in which we introduce the COCOA code that can use the output of star cluster simulations to create mock observations that can be compared with photometric observations of GCs. Application of this code to results of numerical simulations allows us to be able to directly compare results with observations and identify observed GCs that are best reproduced by the simulated clusters. COCOA was used

to simulate observations of simulated GC models that contain a large population of single BHs and helped in identifying observational signatures for the presence of BHs in these GCs.

We also briefly discuss works that have been submitted and are in progress which deal with identifying GCs that could contain a subsystem of stellar mass BHs. Since the early nineties, it had been theorized that GCs deplete their BH population, very quickly. However, over the past decade there has been increasing theoretical and observational speculation that certain GCs contain a sizeable population of BHs. A subsystem of stellar mass BHs in GCs plays a crucial role in its dynamical evolution. We find that simulated GCs which have a significant BH subsystem at 12 Gyr have observational properties that can be correlated with the properties of this BH subsystem. Using these correlations, we identify about 29 Galactic GCs that may contain a sizeable population of BHs. We also present preliminary results from a study in which we investigate ejected populations of BH X-ray binaries from GCs.