Lidov-Kozai mechanism in shrinking Massive Black Hole binaries

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Massive black hole (MBH) binaries are considered to be formed after mergers of galaxies, and are one of the most important targets for the laser interferometer space antenna (LISA). By detecting gravitational waves from MBH binaries, we will be able to examine gravitational theories in the strong field regime, in addition to astrophysical information related to galaxy formation and evolution. Meanwhile, a MBH is expected to have associated star clusters. It has been pointed out that the infall rates of stars would be significantly enhanced for MBH binaries, compared with single MBHs. The infalling stars also emit gravitational waves and electro-magnetic waves, and will work as key probes to study MBHs. Here, the Lidov-Kozai mechanism may play an important role.

The Lidov-Kozai mechanism is a well-known process in celestial mechanics, and works for inclined hierarchical triple systems. In the present case, a MBH and a near-by star form the inner binary and the secondary MBH is the outer perturber. In the Lidov-Kozai mechanism, the inclination and the inner eccentricity oscillate owing to the exchange of angular momenta between the inner and outer orbits. In some cases, the inner eccentricity of the star can be excited to ~ 1, and stars can closely approach MBHs. The Lidov-Kozai mechanism has been actively applied to various astrophysical systems and studied.

The Lidov-Kozai mechanism is caused by the tidal force of the outer perturber, and the inner apsidal precession is crucially important. But, non-Keplerian potentials can suppress the Lidov-Kozai mechanism by generating additional apsidal precessions. Therefore, if the outer body is far away, and the apsidal precession is dominated by other non-Keplerian potentials, the inner eccentricity could not be amplified appreciably.

For our hierarchical triple systems involving MBH binaries, general relativistic corrections and the potential of nuclear star clusters around each MBH correspond to such non-Keplerian potentials. In the long run, the distance between two MBHs will shrink owing to dissipative effects such as dynamical friction, scattering of stars and gravitational wave emissions.

Therefore, though initially suppressed, the Lidov-Kozai mechanism could become gradually effective, competing with other non-Keplerian potentials. However, this transition has not been investigated adequately.

In this thesis, we examine how the "slow" contraction of the outer massive black hole affects the star cluster. Here, "slow" means that the timescale of the contraction is larger than that of the Lidov-Kozai mechanism. Based on the secular perturbation theory, we find that the eccentricities of the stars could show sharp transitions, depending strongly on their initial conditions. By examining the phase-space structure of an associated Hamiltonian, we show that these characteristic behaviors are partly due to a probabilistic bifurcation at a separatrix crossing, resulting from the retrograde apsidal precession by the cluster potential. We also show that separatrix crossings are closely related to realization of a large eccentricity and could be important for astrophysical phenomena such as tidal disruption events or gravitational wave emissions.