平均運動共鳴軌道における惑星系の軌道安定時間に対する惑星中心星質量比の変化の影響

The orbital stability of planets in resonances: the evolution of mass ratio

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Many systems composed of Earth or super-Earth sized planets are observed to date (e.g., Gillon et al., 2017). In some systems, three or four adjacent planets are in a series of mean motion resonances, called resonant chains (Mills et al., 2016; Luger et al., 2017). The resonant chain can be reproduced when the planets migrate inward (e.g., Ogihara & Ida 2009; Izidoro et al., 2017; Bitsch et al., 2019). After gas depletion, planets in resonant chain become orbitally unstable when their number exceeds the critical number that the planets are stable in resonance (Matsumoto et al., 2012). Izidoro et al. (2017) showed over half systems hold more than five planets in their simulations that planets are stable in resonant chain after gas depletion. The disagreement of the number of planets in resonant chain between observations and simulations can be explained by some mechanism reduces the orbital stability of planets in resonances.

The mass ratios between planets in close-in orbits and their central stars would not keep the same value after their formation. There are some mechanisms that super-Earths lose their envelopes, e.g., energy limited escape (Owen 2018). Also, young stars lose their mass by the stellar wind and coronal mass ejection (Cranmer 2017).

We perform simulations that the planets trapped in the first order resonant chain considering their mass ratio change. At first, planets migrate in the disk gas and are trapped in the resonant chain composed of the same resonant commensurability. Then, the disk gas is removed and the mass ratio between planets and the central star is changed, exponentially. When the number of planets in resonant chain exceeds the critical number corresponding resonant chain, their crossing time increases as the mass ratio decreases since the separation normalized by Hill radii becomes larger. In the cases that the resonant systems hold less planets than the critical number, planets sometimes cause orbital instability when their mass ratios change. In some conditions, the orbits of planets in resonant chain become unstable, when their mass ratios decrease only a few percent. Such instabilities tend to occur in systems that hold more planets.

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