Survival of extrasolar short-period planets during stellar contractions

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We study the necessary condition for the survival of short period planets in the multiple planet systems during the epoch of protostellar disk depletion and stellar contractions.

More than 100 extrasolar planets have been discovered, and it is observationally known that about 10% of solar type stars are accompanied with planets. Since the radial velocity technique is mainly used for planetary detection, the orbits and sizes of those discovered extrasolar planets are very different from planets in our solar system.

There is a group of the Jovian planets whose period is less than 6 days whose orbits are nearly circular due to the tidal dissipation within their envelopes (Rasio et al. 1996). When the short period planets have large eccentricities, the tidal dissipation of energy during the circularization would induce their interior heating, inflation, Roche lobe overflow, and mass losses. Therefore, the eccentric hot Jupiters cannot retain their short periods (Gu et al. 2003). In the stage of gaseous planet formation, the host stars are in pre-main stage and are surrounded by the protoplanetary disks. The observed pre-main-sequence stars have a uniform distribution of relatively short rotation periods (Stassun et al.1999). As the host stars evolve to the main sequence, the stellar radii and the speed of rotation change and the disks are depleted. The orbits of short-period planets also evolve as the change of background potential.

In this study, we included not only the potential of the evolving disk and the potential due to the flattening of the star produced by the stellar rotation, but also effect of the post-Newtonian potential of the host star, the tide from the planet, and gravity from other planets. We found that the short-period planets orbiting around young stellar objects whose spin periods are longer than a few days may be highly vulnerable to the dissipation of the disk and evolution of the stars. In the slow rotating star, a resonance between the planets arises as the potential changes and the planets exchange their energy. When the outer planet has relatively high eccentricity and larger mass, the orbit of inner planet, which is originally circularized by the stellar tide, is excited easily thus lost through the subsequent circularization process. Even if the mass of the two planets are comparable, the probability of being lost by the resonance during the spin down is also high.

A loss of less massive short-period planets cannot be avoidable unless the host star had a sufficiently fast rotation to provide a more rapid planetary precession. For example, a survival of planet B around Upsilon Andromeda (0.059AU) would be possible only if the initial spin period of Upsilon Andromeda was shorter than 3 days and it spun down well after the depletion of the disk. But in the systems of three or more planets like the Upsilon Andromedae system, a strong restriction will be imposed on rotation periods of the central star and Q values, since there are several resonances. We suggest that the short-period planets in the multiple planetary system are less stable due to the change of background potential.

Reference

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