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The evolution of multiple planets in radiative disks

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Abstract

Among the observed extrasolar planetary systems there is a high fraction of resonant configurations, which are believed to have formed through a convergent migration process. Here, the differential drift of planets in disks leads to a reduction in radial distance and eventual resonant capture. The final resonance that is reached depends on the physical parameter of the disk and the embedded planets. We will present various outcomes of such a migration process for a pair of planets in isothermal and radiative disks, which will be directly compared to known extrasolar systems.

1. Observed systems in resonance

The resonant configurations of observed extrasolar planets range from 2:1 (GJ 876, HD 73526, HD 128311) over 3:1 (HD 60532) to 3:2 (HD 45364). All of these systems have been explained successfully by a convergent migration process of a pair of planets in isothermal disks. Here, the outer planet migrates at a faster speed than the inner one and the distance between the two planets diminishes. When the two periods are close to a commensurability resonant excitation occurs, which leads to a capture if the migration speed is in a certain range. Using this idea, all the above systems could be modelled by embedding two planets of the observed masses into an isothermal disk. The observed characteristics of individual systems can then be explained by appropriate conditions in the disk, and the planet mass ratio. For the best studied case of GJ 876 the evolution leads to a system where the planets are located deep in the 2:1 resonance with apsidal locking. On the other hand, the resonance is partly broken in systems such as HD 73526 and HD 128311, which may require a scattering event after resonant capture.

Recent, new additions are the system HD 37124 (2:1) and several Kepler candidates, either in 2:1 resonance or close to it. The interesting feature about the Kepler multi-planet systems is their extreme flatness which is much tighter than in the solar system.

2. Planets in radiative disks

So far the dynamical evolution of planetary systems has been studied primarily for planets embedded in isothermal disks. Recently however, it has been found that the thermodynamics of the disk plays a major role in determining the speed **and** direction of migration. The effect is driven by the corotation effects which can overwhelm the standard Lindblad torques originating from the spiral arms generated in the disk. For typical disk parameter planets can even migrate outwards up to a mass of about 30-40 M_{earth}. A multiple planet system embedded in a radiative disk has not been studied yet in detail. Due to the fact that the speed of planets is altered significantly for such disks, we might expect significant changes in the resonant capture process. Most interestingly are the so called zero-torque points where a planet would be stalled and not migrate in nor out.

For a system with one planet located at such an equilibrium point and an additional, approaching planet resonant capture may be eased. We will present simulations of a system of planets embedded in fully radiative disks and study their outcome for a variety of disk and planetary masses. The outcome will be compared directly to migration in corresponding isothermal disks, which will allow for a better understanding of the capture process. For selected cases, we will compare the evolution for planets in 2D and fully 3D disks. Finally, we will analyse in particular systems with planetary parameter suitable for the new Kepler systems.