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Gap formation by a planet in a protoplanetary disk considering the change of disk rotation law

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In a protoplanetary disk, earth-sized or larger planets interact gravitationally with the disk and, by this interaction, they can reduce the disk surface density around their orbit. This makes gaps in the gaseous disk. For larger planets, their gaps terminate the disk gas flow across orbits of the planets, which is thought to explain the formation of the transition disks with the inner hole. Many transition disks with inner holes or gap structures have been observed.

In the near future, more detail structures of transition disks will be revealed by the direct imaging by the Atacama Large Millimeter/submillimeter Array (ALMA).

However, the formation of gaps and inner hole by planets is still theoretically uncertain process, and there is no quantitative model to explain the relation between the planet mass and the shape and depth of gaps. The goal of our study is the construction of a formation model for the inner hole and gap around a planet, by using one-dimensional viscous accretion disk model with the disk-planet interaction. In previous studies on the gap formation, the change in the disk rotation law due to the gaseous pressure gradient has been neglected. However, owing to a steep surface density gradient in the gap, the deviation from the Keplerian rotation law can be remarkably large. Moreover, the surface density profile in the gap is strongly influenced by the deviation of the disk rotation law.

In this study, we examine the surface density profile of the gap in a self-consistent way, by taking into account the deviation of the disk rotation law due to the steep surface density gradient. Our results are as follows;

(1). The change of rotation law promotes the viscous angular momentum transfer in the gap, and, as a result, the gap becomes shallower than the evaluation by previous studies. This effect is stronger for a deeper gap, and the depth of the gap is significantly reduced.

(2). Owing to the significant change of rotation law for a deep gap, the Rayleigh criterion that is stable condition for the rotation disk can be broken. In this case, the structure would be shift to the marginally stable state for the Rayleigh criterion (Tanigawa & Ikoma 2007). Solving the gap structure including the breaking the Rayleigh criterion, we find that the viscous angular momentum transfer is promoted by the breaking of the Rayleigh criterion, and then, the depth of the gap is further reduced.

In addition to above results, I want to talk about the comparison between the result of numerical fluid simulation and the results of our model.

Keywords: protoplanetary disk, disk-planet interaction, disk evolution, gap formation