On the Mechanism for Creating Multiple Rings in Protoplanetary Disks: Non-linear Development of Secular Gravitational Instability

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Recent observations have revealed various structures in protoplanetary disks. Especially, we are interested in the origin of the multiple ring-like structures observed by ALMA. One of promising mechanisms for creating multiple ring structures is secular gravitational instability (Secular GI) which is an instability due to the gas-dust friction even in a self-gravitationally stable disk. Previous works, Takahashi & Inutsuka 2014 and 2016, have shown that the ring-like structures in HL Tau disk could form by Secular GI and suggested that the ring formation could lead to the planetesimal formation in the HL Tau disk. These works are based on the local linear analysis. To understand the actual process of the ring formation and the planetesimal formation, however, we need to investigate the non-linear evolution of Secular GI and determine the fate of the protoplanetary disk.

The purpose of this study is to investigate the non-linear evolution by a numerical simulation. Since the growth time is much longer than the Keplerian rotation timescale, we should reduce the numerical error in the time integration as much as possible. We, first, develop a symplectic numerical scheme for hydrodynamical system without dissipation, and then extend the method to include realistic physics such as gas-dust friction. The results of our simulations show that dust goes into the non-linear growth phase much earlier than gas, which raises the dust-to-gas ratio from ~0.1 to more than 1. This implies that non-linear growth of Secular GI may lead to the growth of dust-size and the planetesimal formation.