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SPH Simulations of Protoplanetary Perturbers in Gas Disks

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Abstract. We use Smoothed Particle Hydrodynamics (SPH) to numerically investigate gap clearing around a protoplanetary body in a self-gravitating gaseous disk. It has been suggested that proto-Jupiter regulated it's own growth by clearing a gap around itself and thus halting accretion.

1. Introduction

A massive perturber in a gaseous protoplanetary disk can excite a spiral wave and thus clear the region around the protoplanet of nebula gas. This mechanism has been suggested in determining the final mass of Jupiter and limit that of the other giant planets. Sekiya, Miyama & Hayashi (1987) showed that when the perturber mass was greater than about 0.7 M_{Jup}, a wave was excited. They found that a void was cleared around the protoplanet & accretion halted. Artymowicz & Lubow (1996) suggest that for slightly warmer thicker protoplanetary disks an accretion stream may cross the gap around the protoplanet and continue to accrete matter, thus forming substantially larger objects. We use SPH to investigate these scenarios.

2. Theory of Gap Clearing

The disk–protostar interaction is important in determining the final mass of a protoplanet. Relatively small protoplanet masses will not substantially tidally influence the disk structure. As the protoplanet accretes matter however, it's tidal effects can induce the formation of a gap around the perturbers orbit.

Gap formation is determined by both viscosity and disk thickness – two unknown quantities. Typical models of protoplanetary disks however choose the ratio disk scale height to disk radius, H/R, to be between 0.05 and 0.1. Assuming a turbulent disk, the viscosity α parameter is around 0.01. A necessary condition

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for gap formation (see Lin & Papaloizou 1993) is that the binary ratio, q, (in this case $q = M_{Jup}/M_{\odot}$) satisfy the inequality $q > 3(H/R)^3$.

Recent work by Artymowicz & Lubow (1996) suggests that by modelling a slightly warmer and thicker protoplanetary disk, with say H/R=0.05, that it is possible for the accretion stream to "clear the gap" and continue accretion onto the protoplanet. They suggest that the creation of a disk gap may not be sufficient to stop the growth of the protoplanet, perhaps leading to the formation of brown dwarfs.

3. Model Parameters

We use SPH to model a gaseous protoplanetary disk in Keplerian orbit around the Sun, with a Jupiter-like perturber embedded in it. The disk is self-gravitating ($M_{disk}/M_{sun} = 0.05$) with radial extent 1–10 AU. and a multi-grid Poisson solver is used for the potential. The surface density follows a power law. When using SPH, the artificial viscosity parameters must be chosen with some care. If the viscosity is too low, particle penetration can occur, and if too high, the disk becomes viscously unstable. We choose $\beta = 0$ and $\alpha \approx 0.1$.

Disk particles are accreted onto the perturber if they enter a critical radius (10% of the Hill radius). As the perturber mass increases, so does the Hill radius and thus the self gravity of the perturber becomes more important.

We use two equations of state: adiabatic with a power law temperature distribution, and isothermal with the thin disk approximation to compare our simulations with Artymowicz & Lubow.

4. Simulations Results and Discussion

We find that for bodies with $M_{pert} \geq 0.5 M_{Jup}$ the pressure effects of the nebula gas can be overcome and the gravitational field of the perturber dominates the disk. We do however find that simulation results are quite sensitive on the disk temperature profile (or H/R). For many models, a Jupiter mass perturber is not enough to fully clear a gap around the body (i.e. halting accretion) after 50 perturber orbits. More massive perturbers (say $5M_{jup}$) seem to be required to fully clear a void around itself and *then* the possibility of gap crossing can be investigated. Perhaps brown dwarfs can only be formed in thicker protostellar disks and from more massive progenitor bodies.

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