Effects of Thermodynamics On the Accretion of Gas Giants

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1.Introduction

The runaway process is a crucial stage in the formation of planets, as it is during this phase that the gas giants acquire majority of their masses. [1] Accretion onto the planet is dependent on the circumplanetary disk (CPD) and is influenced by spiral density waves induced by planets whose intensity and structure are strongly impacted by the thermodynamics of the protoplanetary disk (PPD). [2]

2.Method

- Global 2D simulations with FARGO3D. [3]
- Resolution: 1400 grids in radial, 1500 grids in azimuthal.
- Sink particle with mass of one Jupiter.
- Thermodynamics: locally isothermal, adiabatic, and adiabatic with cooling to simulate the transition between them. (cooling timescale ranges from 0.01 to 10)

3.Results

3.1 Structure of the PPD

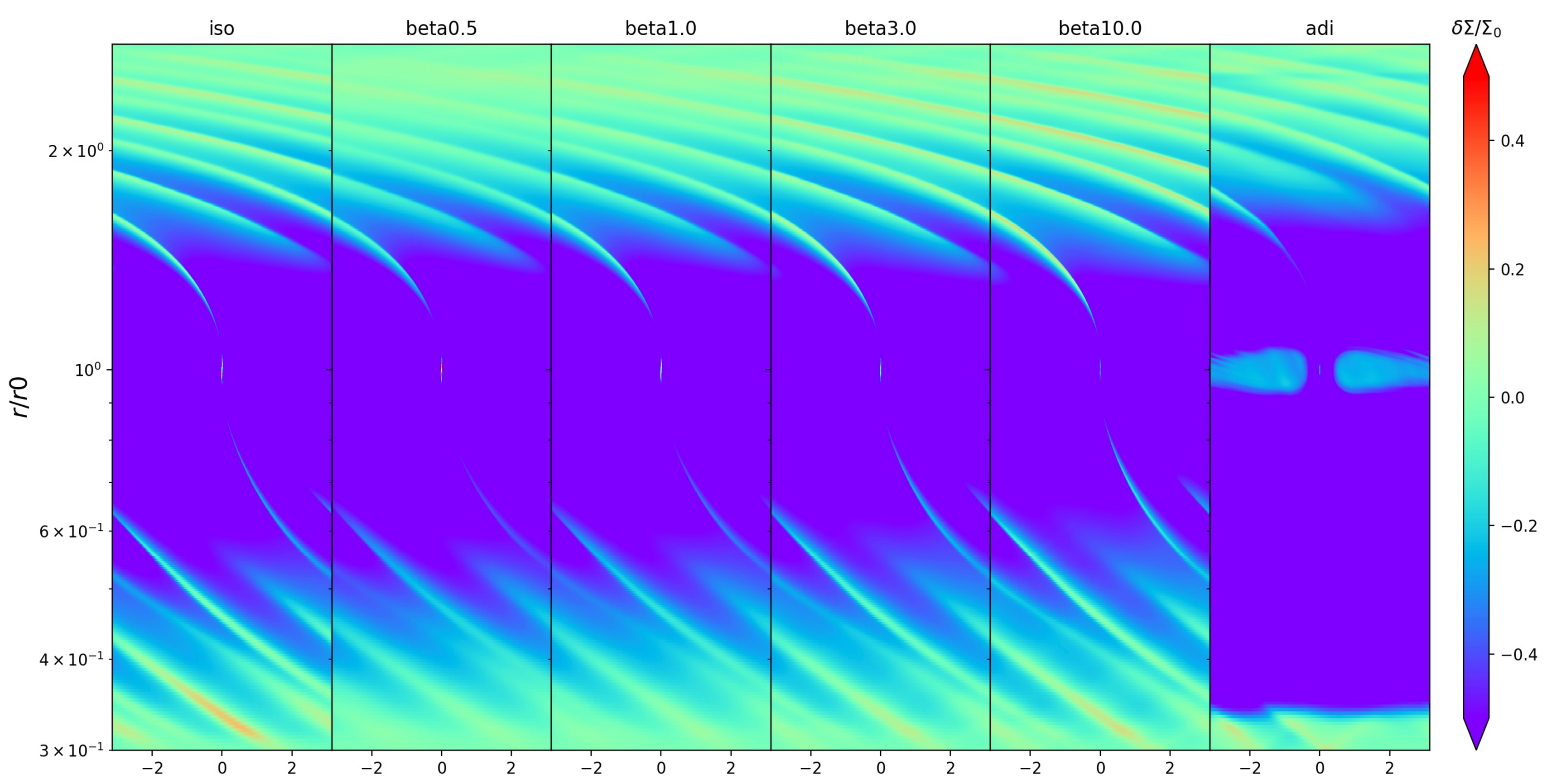

Figure 1: The density perturbation profile of different simulations at 1000 orbits. From left to right, the disks represent fast to slow cooling. The isothermal disk is shown in the leftmost panel, with adiabatic disk in the rightmost panel. r_0 and Σ_0 are the position of the planet and the initial density at r_0. The dimensionless disk cooling parameters beta, which are equal to cooling timescales at r_0, are 0.5, 1, 3 and 10 respectively.[4]

3.2 Accretion rate of the planet

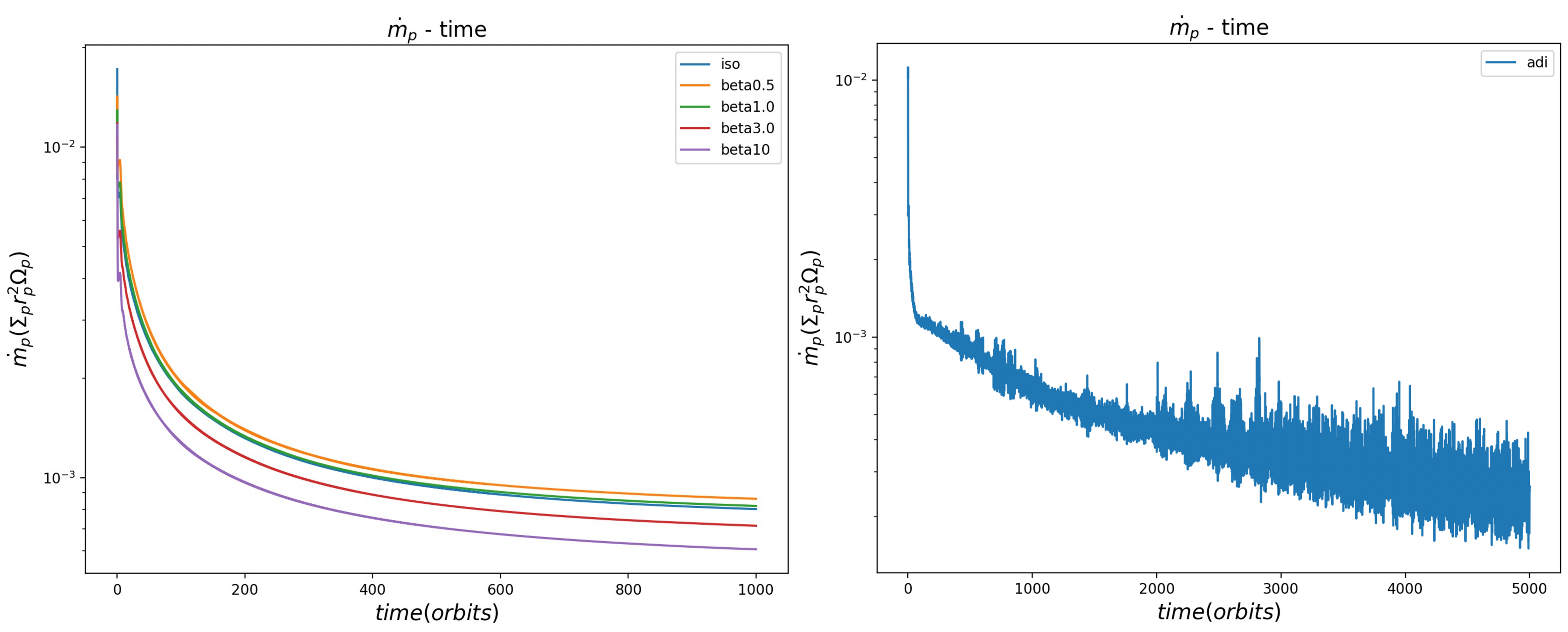

Figure 2: Accretion rate of the planet at different time in unit of $\Sigma r^2 \Omega$ at r_0. The left panel shows the accretion rate in isothermal disk and different cooling timescales at 0-1000 orbits. The right panel shows the accretion rate with adiabatic state at 0-5000 orbits.

- Difference between isothermal case and low beta($\leq$1) cases are relatively small.
- The accretion rate in isothermal case is 4 times larger than the adiabatic which is enough to make a significant impact on the time scale of the planet's runaway growth.
- The accretion rate gradually decreases towards the adiabatic case with the increase of the cooling timescale, indicating that the beta cooling method is appropriate.

3.3 Mass flux around the planet

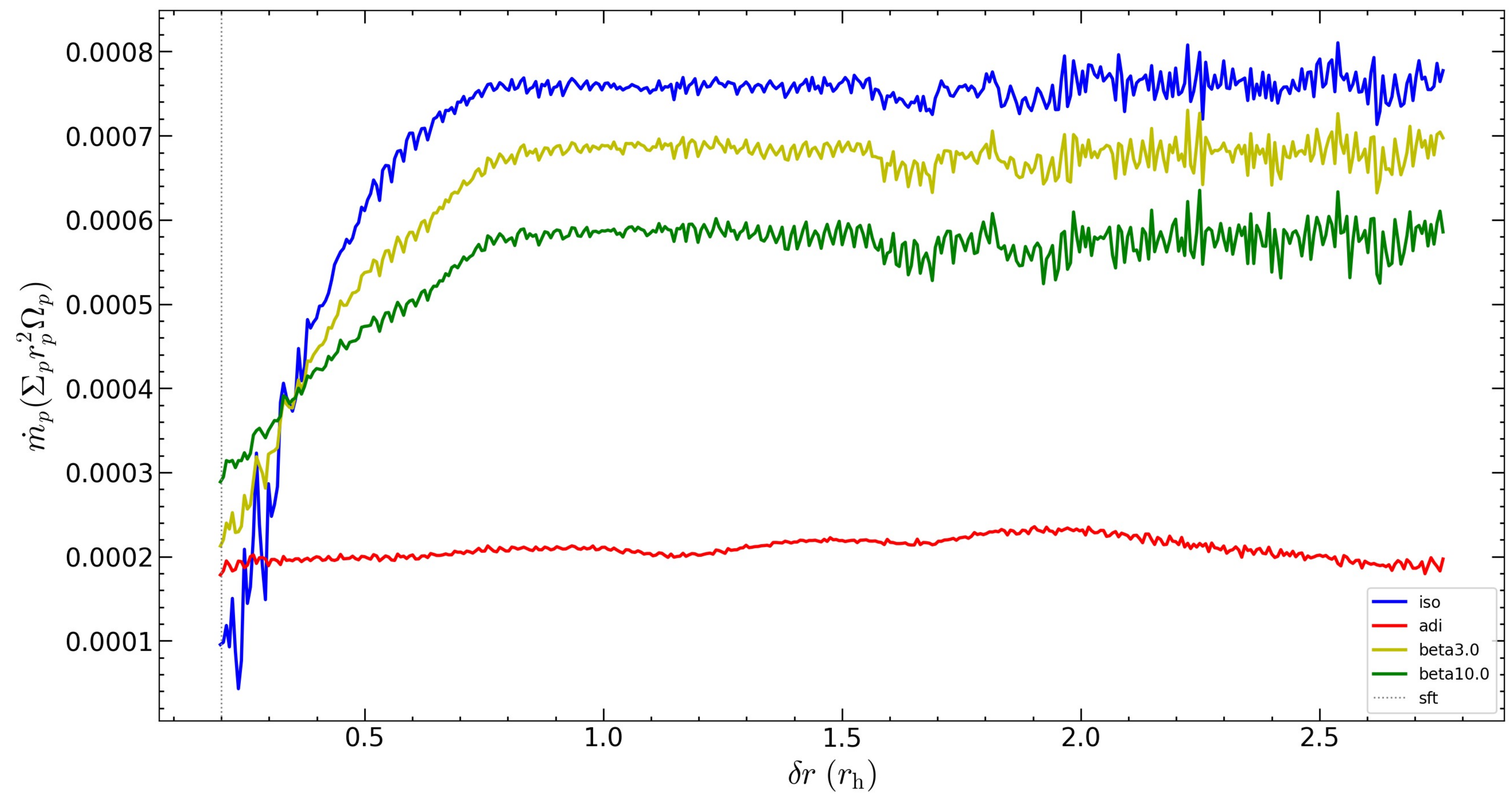

Figure 3: The azimuthally averaged mass flux around the planet. The grey dashed line represents the softening length in our simulations, which is 0.2 Hill radius. The value of the approximately steady mass flux beyond 0.5 Hill radius is consistent with the result in Figure2.

3.4 Properties of the CPD

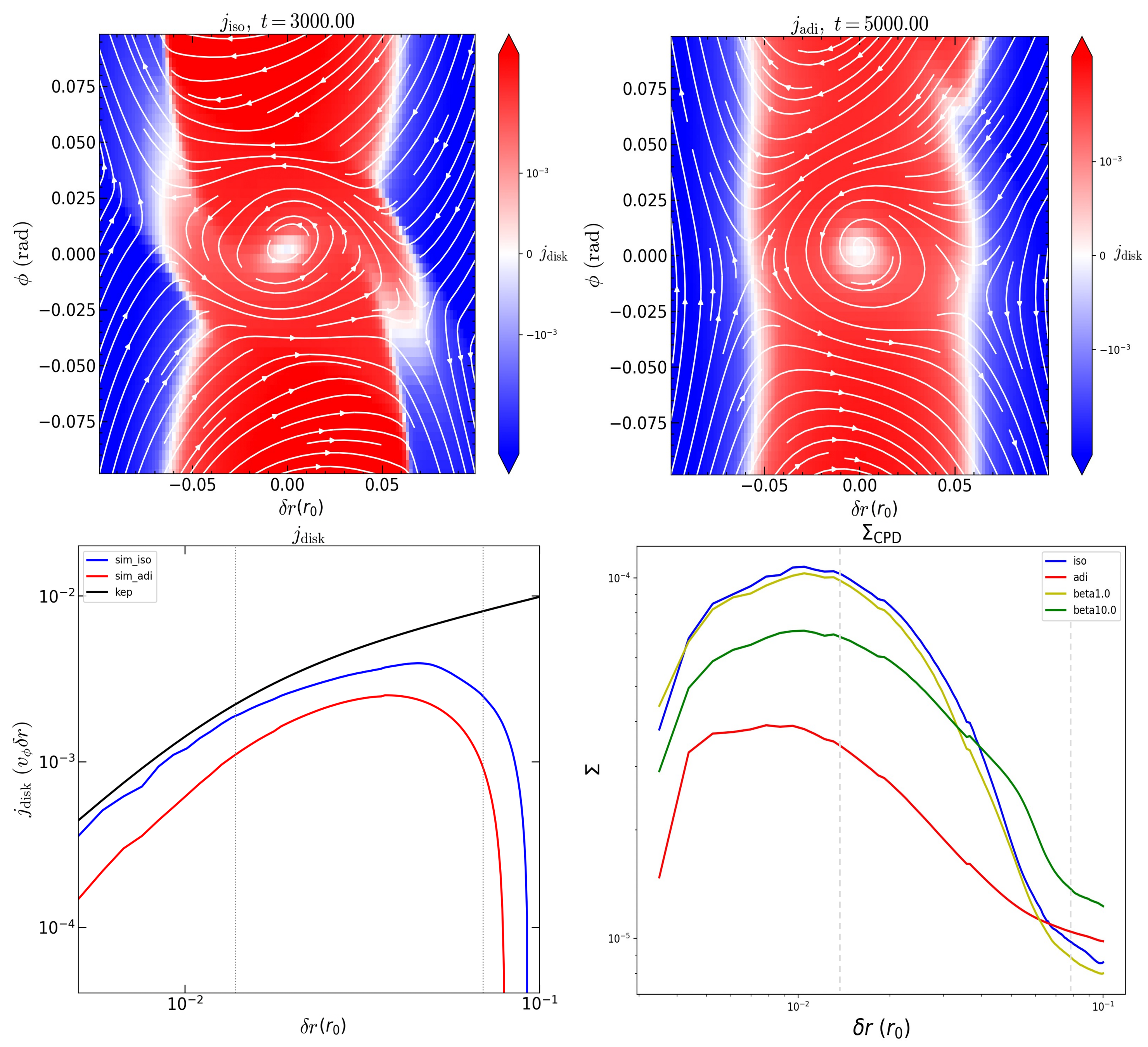

Figure 4: Upper panels: velocity field in the rotating frame of the planet, isothermal disk at 3000 orbits on the left and adiabatic disk at 5000 orbits on the right. Lower panels: left is the azimuthally averaged angular momentum relative to the planet. The black line represents the calculated rotation curve from the Keplerian motion. Two dashed lines represent softening length and Hill radius respectively. Right is the density profile of CPD at 1000 orbits, and the density is in code unit.

4.Conclusions

- The thermodynamic properties of planetary disks have a great impact on the accretion process of gas giants. 4 times difference in accretion rate exists between isothermal disk and adiabatic disk .
- This difference is closely related to properties of the CPD, for which the disk is smaller in size and less rotation supported in the adiabatic case than in isothermal one [5,6].
- Further 3D simulations will be carried out in the next step to quantify the effect of the meridional flow on the accretion dynamics[5]. The accretion mechanism also needs more analysis to verify[7].

5.References

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