The growth of protoplanets via the accretion of small bodies in perturbed disks

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In the last ten years, the growth of protoplanets is considered via the accretion of cm-m sized particles (pebbles) as well as km sized planetesimals.Such small bodies feel strong gas drag due to the gas flow and atmospheric structure around the protoplanet.This gas drag plays an important role to determine the collisional cross section between small bodies and planets.
In this study, we perform three dimensional hydrodynamical simulations for a protoplanetary disk around a protoplanet and calculate orbits of mm-sized to km-sized bodies in the protoplanetary disk perturbed by the protoplanet.
We investigate the gas flow of the protoplanetary disk perturbed by the gravity of the protoplanet with Earth mass via three dimensional hydrodynamical simulations.The atmosphere is generated being isolated envelope around the protoplanet. The characteristic gas structures are formed in vicinity of the atmosphere. The horseshoe flow extends along the orbital direction of the planet in the anterior-posterior direction of the planet.
We calculate orbits of bodies in the gas structure obtained by the hydrodynamical simulation. The orbits are characterized by the dimensionless stopping time, St, due to gas drag. The orbits are strongly affected by the atmosphere for $St > 1$, while the gas flow plays an important role for $St < 1$. The velocity of the bigger particles ($St > 0.1$) can be exceeded the sound velocity due to the gravity of the planet.
Finally, we estimate the collision rate (Pcol) between particles and the planet based on the orbital calculations.
The atmosphere decelerates in the vicinity of the planet, while the gas flow drifts bodies to the planets. Such effects assist bodies in accreting onto the planet. As a result, Pcol for St ˜ 0.1-100 is larger than the gas-free limit.
Considering the effects of the atmosphere and gas flow, we derive the new analytic formula for the collision rate, which is in good agreement with our simulations.

Keywords: pebble accretion, protoplanetary disk, planet formation

