# Gas flow around low mass planets in a protoplanetary disk: the dependence of out-flow speed on the planetary mass

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The Kepler mission has revealed that about half of Sun-like stars harbor short period super-Earths. These bodies have radii a few times larger than Earth's radius. Short period super-Earths have avoided runaway gas accretion and growth to gas giants, which is the apparent contradiction to planet formation theory. The formation of short period super-Earths have not been fully elucidated.

Previous studies had found that gas enters the Bondi sphere of a planet embedded in a protoplanetary disk at high latitudes and exits the Bondi sphere in the mid-plane regions [e.g., 1]. The atmospheric recycling delays cooling and shrinking of the gaseous envelope, which is expected to be able to explain the formation process of short period super-Earths. Also, if the outflow speed is sufficiently high, the flow field around the embedded planet may reduce the accretion rate of solid materials (e.g., pebbles). The importance of the flow field depends on the changes of the gas flow as a function of the mass of the planet. However, since the calculation settings are different, it is difficult to simply compare previous studies. Therefore we investigated the dependency of the flow field on the planetary mass.

This study simulated the gas flow around a low mass planet embedded in a protoplanetary disk. In this study, we performed three dimensional, isothermal, inviscid hydrodynamical simulations and investigated how the nature of the flow field changed as a function of the planetary mass.

We found that the gas enters high latitudes of the Bondi sphere and leaves through the midplane, regardless of the assumed planetary mass. Furthermore, we clarified that the density and speed of the gas flow changed as a function of dimensionless planetary mass m=(the Bondi radius)/(the disk scale-height). On the other hand, the topology of the flow field did not significantly changed as a function of m. The outflow speed from the Bondi sphere of the planet having 1 $M_{\oplus}$ and orbiting near the central star (<1 au) reached at ˜ 0.4 $c_s$. From an analytical estimation, we found that the outflow speed can be expressed as $|u_{out}| \propto m c_s$ ($R_{Bondi} \leqq R_{Hill}$) or $|u_{out}| \propto m^{1/3} c_s$ ($R_{Bondi} \geqq R_{Hill}$). Based on our results, it will be possible to discuss the effect of the outflow on the pebble accretion with comparing the timescale where the outflow crosses the Bondi/Hill region and specific timescales related to the pebble/dust accretion.

[1] Ormel, C. W., et al. (2015), MNRAS, 447, 3512.

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