An Explanation for Physical Mechanism of the Streaming Instability

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Planets are thought to be formed from planetesimals, which are 1-100 km in size, and planetesimals are formed by accumulating small dust particles. Dust particles of a size of 10 cm-1 m drift sunward at 1 au per a century. Dust particles must grow within a timescale faster than this sunward drift timescale limit, otherwise they cannot form planetesimals. Enhancement of the particle density leads to the self-gravitational instability if the density reaches the Roche density, and the dense dust particles form planetesimals. In this case, the dramatic radial drift of dust particles can be avoided. Youdin & Goodman (2005; YG05) discovered that dust and gas streams mutually interacting via drag force generate local linear instability and a particle clumping occurs. This instability is called the streaming instability (SI). A lot of linear and non-linear numerical simulations conducted and it has been confirmed that SI emerges under certain conditions. But the physical mechanism of SI is not clear yet, because the order of the dispersion relation is as high as 6 and the mechanism seems to be difficult to understand. Applying the terminal velocity approximation (YG05) to particle continuity equation and gas incompressibility, Jacquet, Balbus, & Latter (2011; JBL11) attempted to give a physical explanation about the SI mechanism. Their explanation was as follows:

1. The gas pressure maximum traps dust particles.

2. Dust particles drag the gas toward the gas pressure maximum.

3. The gas pressure maximum is strengthened. Though the gas pressure gradient tends to force out the gas from the maximum, the dust particle drag force on the gas and the Coriolis force make roles to keep the geostrophic balance.

JBL11 suggested the explanation of the mechanism in which all the motion takes place only in the midplane, however, YG05 emphasized that the vertical advection flows toward the density maximum and it dominates the flow in the midplane.

In this study, first, we conduct an analysis on the dispersion relation that employs the terminal velocity approximation (YG05) and calculate phase differences among the perturbed particle density, the perturbed gas pressure, and the perturbed particle velocities for an unstable mode. Then, we give an explanation about the mechanism of SI including the vertical motion unlike the explanation by JBL11.

Our explanation on the SI mechanism is as follows:

1. At the particle density maximum, the gas receives more angular momentum, while at the particle density minimum, the gas receives less. So, the gas radial velocity perturbation and the gas pressure fluctuation along the radial direction are generated.

2. Toward the gas pressure minimum, the gas flows in vertically with dragging dust particles. On the contrary, both gas and dust particles flow out vertically from the gas pressure maximum.

3. The phase velocity of the dust particle density maximum is negative so the particle density maximum moves radially inward. The density maximum encounters the dust particle input due to the vertical converging flow and the density maximum is enhanced.

This explanation is consistent with solutions of the linear stability analysis. In addition, the explanation seems physically reasonable and easy to understand.

Keywords: Streaming Instability, protoplanetary disk, protoplanetesimal formation, hydrodynamics, linear stability analysis

