Forming Planetesimals by Gravitational Instability: I. The Role of the Richardson Number in Triggering the Kelvin-Helmholtz Instability

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Gravitational instability (GI) of a dust-rich layer at the midplane of a gaseous circumstellar disk is one proposed mechanism to form planetesimals, the building blocks of rocky planets and gas giant cores. Self-gravity competes against the Kelvin-Helmholtz instability (KHI): gradients in dust content drive a vertical shear which risks overturning the dusty subdisk and forestalling GI. To understand the conditions under which the disk can resist the KHI, we perform 3D simulations of stratified subdisks in the limit that dust particles are small and aerodynamically well coupled to gas. This limit screens out the streaming instability and isolates the KHI. Each subdisk is assumed to have a vertical density profile given by a spatially constant Richardson number Ri. We vary Ri and the midplane dust-to-gas ratio mu and find that the critical Richardson number dividing KH-unstable from KH-stable flows is not unique; rather Ri_crit grows nearly linearly with mu for mu=0.3-10. Only for disks of bulk solar metallicity is Ri_crit ~ 0.2, close to the classical value. Our results suggest that a dusty sublayer can gravitationally fragment and presumably spawn planetesimals if embedded within a solar metallicity gas disk ~4x more massive than the minimum-mass solar nebula; or a minimum-mass disk having ~3x solar metallicity; or some intermediate combination of these two possibilities. Gravitational instability seems possible without resorting to the streaming instability or to turbulent concentration of particles.

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