Forming Planetesimals by Gravitational Instability: II. How Dust Settles to its Marginally Stable State

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Dust at the midplane of a circumstellar disk can become gravitationally unstable and fragment into planetesimals if the local dust-to-gas density ratio mu is sufficiently high. We simulate how dust settles in passive disks and ask how high mu can become. We settle the dust using a 1D code and test for dynamical stability using a 3D shearing box code. This scheme allows us to explore the behavior of small particles having short but non-zero stopping times in gas: 0 < t_stop << the orbital period. The streaming instability is thereby filtered out. Dust settles until shearing instabilities in the edges of the dust layer threaten to overturn the entire layer. In this state of marginal stability, mu=2.9 for a disk whose bulk (height-integrated) metallicity is solar. For a disk whose bulk metallicity is 4x solar, mu reaches 26.4. These maximum values of mu, which depend on the background radial pressure gradient, are so large that gravitational instability of small particles is viable in disks whose bulk metallicities are just a few (<4) times solar. Earlier studies assumed that dust settles until the Richardson number Ri is spatially constant. Our simulations are free of this assumption but provide support for it within the dust layer's edges, with the proviso that Ri increases with bulk metallicity in the same way that we found in Paper I. Only modest enhancements in bulk metallicity are needed to spawn planetesimals directly from small particles.

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