Large-scale Planetesimal Formation by Streaming Instability

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It has been a long standing problem in core accretion scenario of planet formation for meter/decimeter-sized solid objects to remain in the gaseous protoplanetary disks due to constant head wind (Weidenschilling 1977, MNRAS). One of the promising mechanisms to overcome this meter-barrier is the streaming instability (Youdin & Goodman 2005, ApJ), in which viscous interaction between solids and gas can concentrate the solids to the extent that gravitational collapse takes over to produce Ceres-sized planetesimals (Johansen et al. 2007, Nature). Systemic study of this mechanism seems warranted to explore the preferable conditions and the properties of the resulting solid concentration.

We conduct the largest-scale simulations of this kind to date, up to 0.8H both horizontally and vertically, where H is the gas scale height. We use the *Pencil Code* to model a local shearing box of gas and solid particles. The vertical component of the stellar gravity is included so that the particles quickly settles into a thin mid-plane layer. The gas and particles interacts by viscous drags with a Stokes number of 0.3. The total solid-to-gas ratio is fixed at 0.02.

The top panel of Figure 1 demonstrates the process of particle sedimentation and turbulent stirring. The particle scale height first decreases to a minimum within about one local orbital period and then increases due to stirring by the streaming instability. The latter process can also be seen in the top panel of Figure 2. There exists a significant increase in particle scale height when increasing the vertical size of the simulation box from 0.2H to 0.4H, while the results are similar for runs of vertical sizes 0.4H and 0.8H. This indicates there exists a minimum vertical size of about 0.4H to properly capture the turbulent stirring of particles by streaming instability.

Furthermore, the concentration of particles by streaming instability seems also dependent on the dimensions of the simulation box, as shown in the bottom panels of Figures 1 and 2. The larger the horizontal dimensions, the higher the peak particle density. On the other hand, the peak particle density seems little affected by the vertical dimension of the simulation box. This phenomenon could be understand by the difference in the size of the particle feeding zone in the azimuthal direction.

Figure 3 shows the particle density, integrated over both the vertical and the azimuthal directions, as a function of time and radial position. Multiple concentrations at different radii can be seen given large enough horizontal dimensions. For a 0.8H×0.8H×0.8H simulation box, at least two particle concentrations exist simultaneously. This indicates that we might have captured the characteristic wavelength of particle concentrations in the nonlinear stage of the streaming instability.

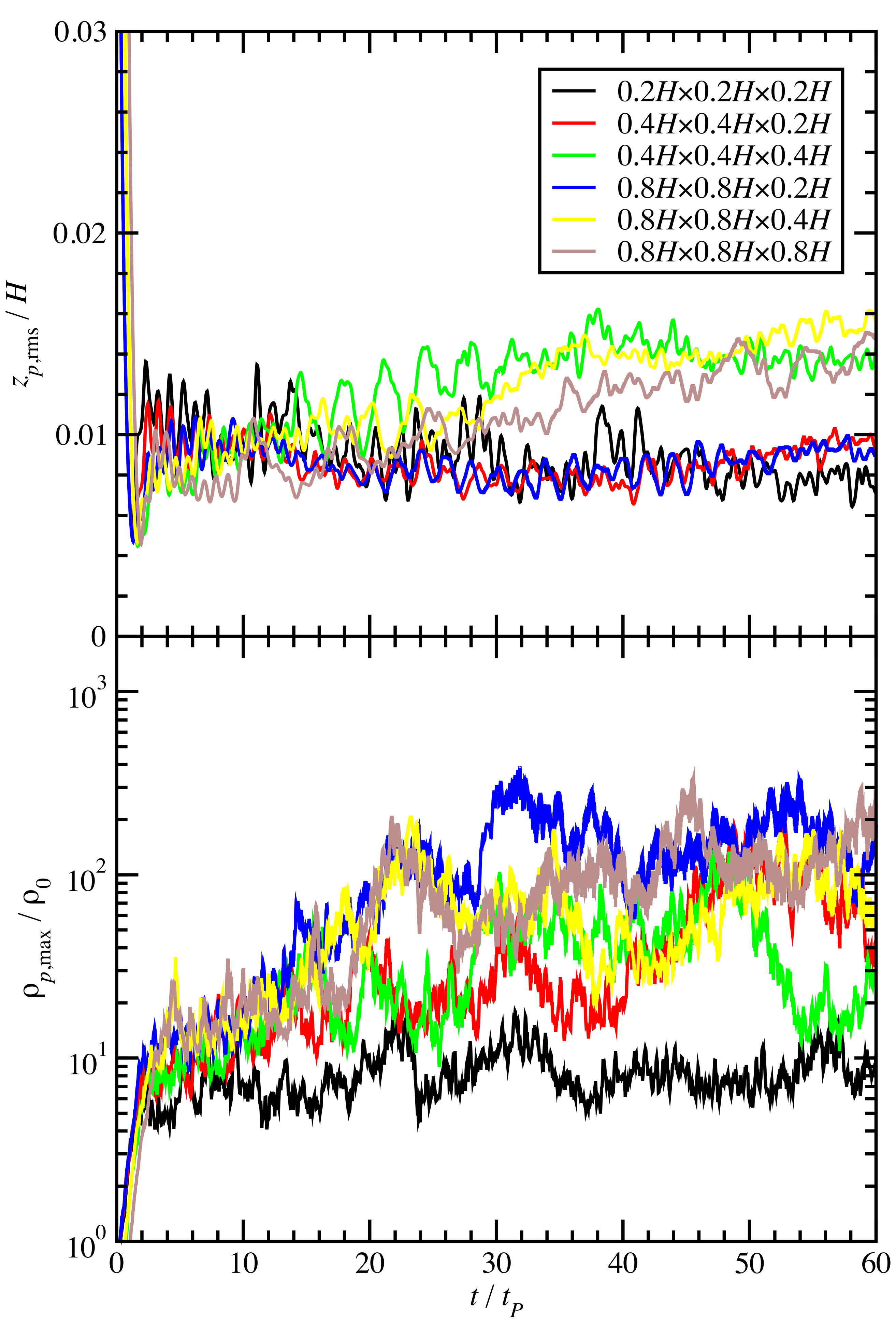

Figure 1—Average particle scale height (top) and maximum particle density (bottom) as a function of time in terms of the local orbital period. Lines of different colors denote simulation boxes of different dimensions, where H is the gas scale height.

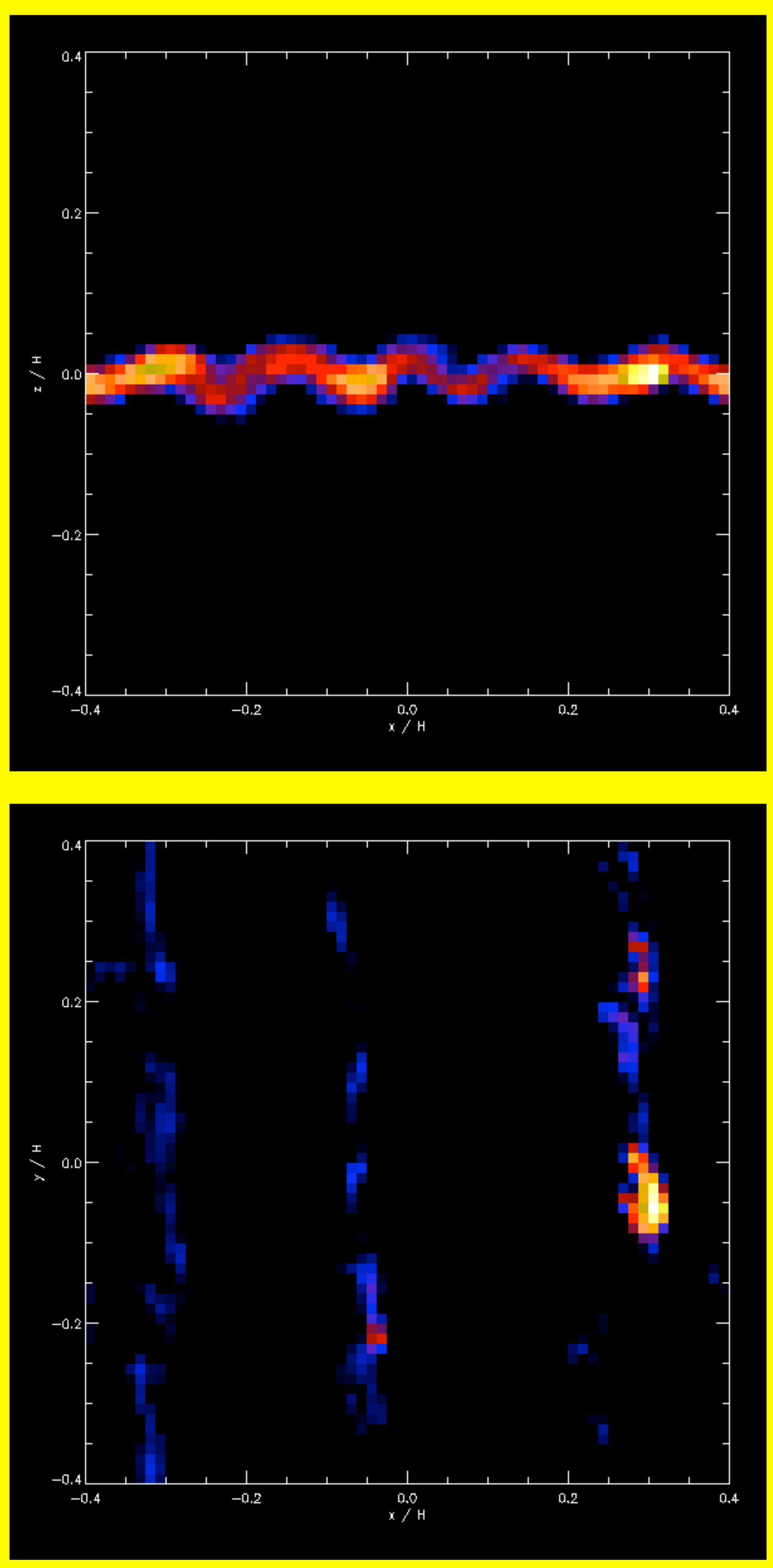

Figure 2—A snapshot of the particle column densities in azimuthal direction (top) and in vertical direction (bottom) from a 0.8H×0.8H×0.8H simulation box.

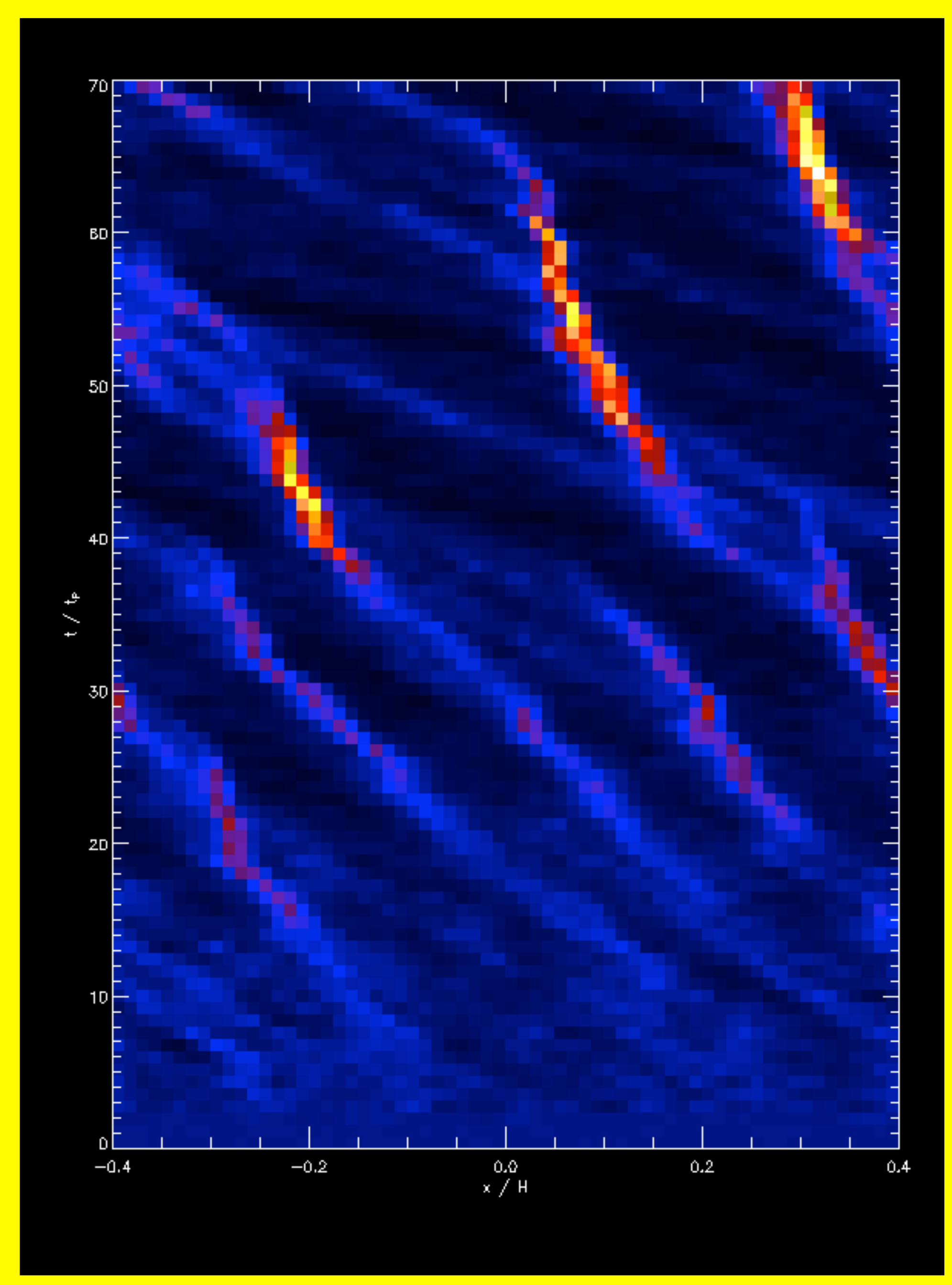

Figure 3—Space-time diagram of the particle density integrated over each yz-plane from a 0.8H×0.8H×0.8H simulation box. The horizontal axis represents the radial direction, while the vertical axis denotes the time.