On the Feeding Zone of Planetesimal Formation by the Streaming Instability

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Motivation

- Meter-size barrier: Inward drift timescale of cm/m-sized solids is short compared to the disk lifetime due to frictional drag by the gas (so-called head wind) *(Adachi et al. 1976)*.
- The streaming instability is promising to overcome the meter-size barrier and lead to the formation of planetesimals *(e.g., Johansen et al. 2007)*.
- The simulation domain of most previous models was small, much less than one gas scale height.
- Only one filamentary concentration of solids has been observed in the models.
  - Typical separation between filaments is unknown.
- It is not clear if the streaming instability would be interacting with large-scale gas dynamics.

Objectives

- Systematically conduct numerical simulations of the streaming instability with various computational domains.
- Investigate the resulting filamentary structures of solids and their interaction with the gas.

Model Setup

- Local-shearing-box approximation *(Goldreich & Lynden-Bell 1965)*.
- Including vertical gravity of the star:
  - Gas disk is vertically stratified.
  - Solid particles sediment towards mid-plane.
- Frictional timescale: $0.05P$.
  - P: local orbital period.
  - Particle size corresponding to ~70 cm at 1 AU or ~4 mm at 30 AU in the Minimum Mass Solar Nebula *(Hayashi 1981)*.
- Solid-to-gas ratio: 2%.
- Head-wind velocity: 5% the local speed of sound.
- Computational domain: from $0.2H$ to $1.6H$ in each dimension.
  - H: local gas scale height.
- Resolution: $160\ H^{-1}$.
- Simulation code: the Pencil Code.

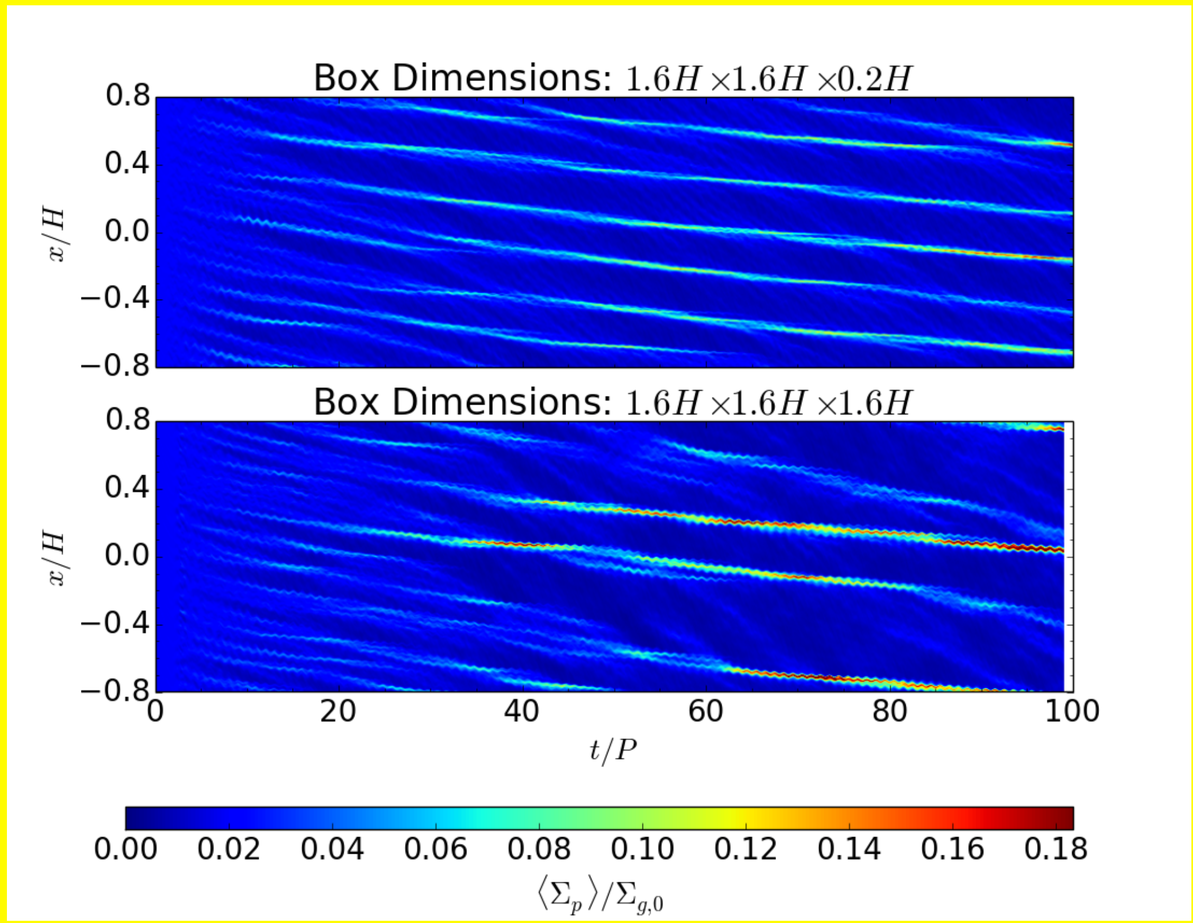
Conclusions

- The solid particles interact with the gas over at least one gas scale height.
- The initial feeding zone of newborn planetesimals is of size $\sim 0.2H$.
- The composition of the asteroids may probe the chemical inhomogeneity of the solar nebula down to this scale.

References

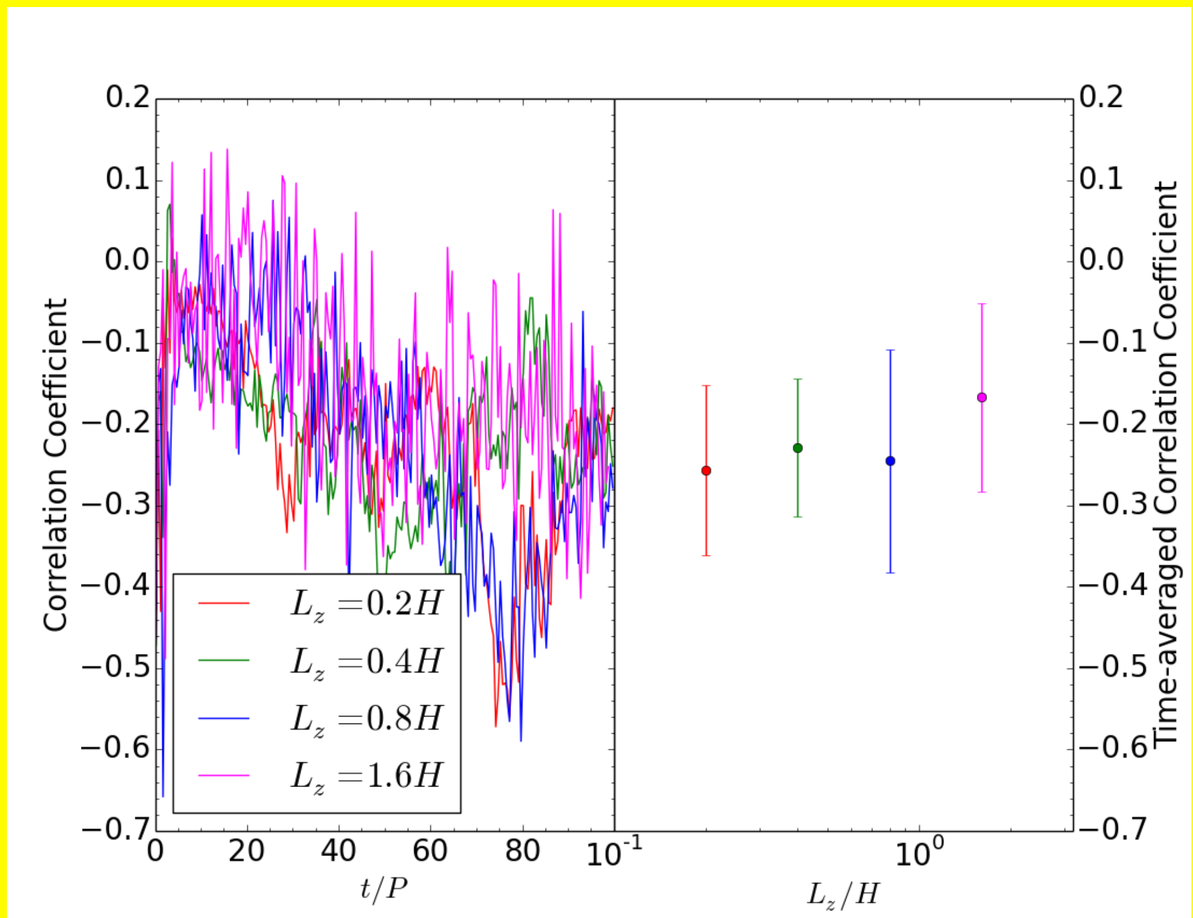
- Adachi, I., Hayashi, C., & Nakazawa, K. 1976, Progress of Theoretical Physics, 56, 1756
- Goldreich, P., & Lynden-Bell, D. 1965, MNRAS, 130, 125
- Hayashi, C. 1981, Progress of Theoretical Physics Supplement, 70, 35
- Johansen, A., Oishi, J. S., Mac Low, M.-M., Klahr, H., Henning, T., & Youdin, A. 2007, Nature, 448, 1022

Radial Particle Concentrations



- Azimuthally averaged column density of solids with respect to that of gas as a function of radial position x and time t.
- Multiple particle filaments are produced.
- The larger the vertical domain, the more chaotic dynamics is observed.
- Typical separation $\sim 0.2H$.

Gas-particle Correlation



- The solid and the gas column densities anti-correlate.
- The gas pressure is slightly enhanced between particle filaments, which may regulate the dynamics of the filaments.
- The larger the vertical domain, the less the anti-correlation, indicating gas motion at relatively high altitude.
- This may explain the increased irregularity of the particle filaments for tall simulation boxes.

For more information,
please see *arXiv:1407.5995*.