Are planet-induced gaps a “leaky sieve” to solids in a protoplanetary disk?

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Abstract

Jupiter's orbit has frequently been proposed as the demarcation between reservoirs of the solar nebula where the non-carbonaceous (NC) and carbonaceous class (CC) of meteorites formed (e.g. Kleine et al., 2020). In this scenario, the young Jupiter carves a gap in its protoplanetary disk, accreting the gas within its feeding zone. The small solids suspended in the gas naturally drift towards the star, but, once a pressure bump forms outside Jupiter's orbit, they pile up at the edge of the gap without crossing. Others (van Kooten et al., 2021) have found that chemical and isotopic analyses of meteorites do not support the idea of two mutually exclusive populations. We propose that a gap cleared by a young, massive planet is not a perfect barrier to dust drift, an idea we explore using a modified version of FARGO3D to simulate, for the first time, the dynamical evolution of solid particles of constant size in a disk with an embedded planet.

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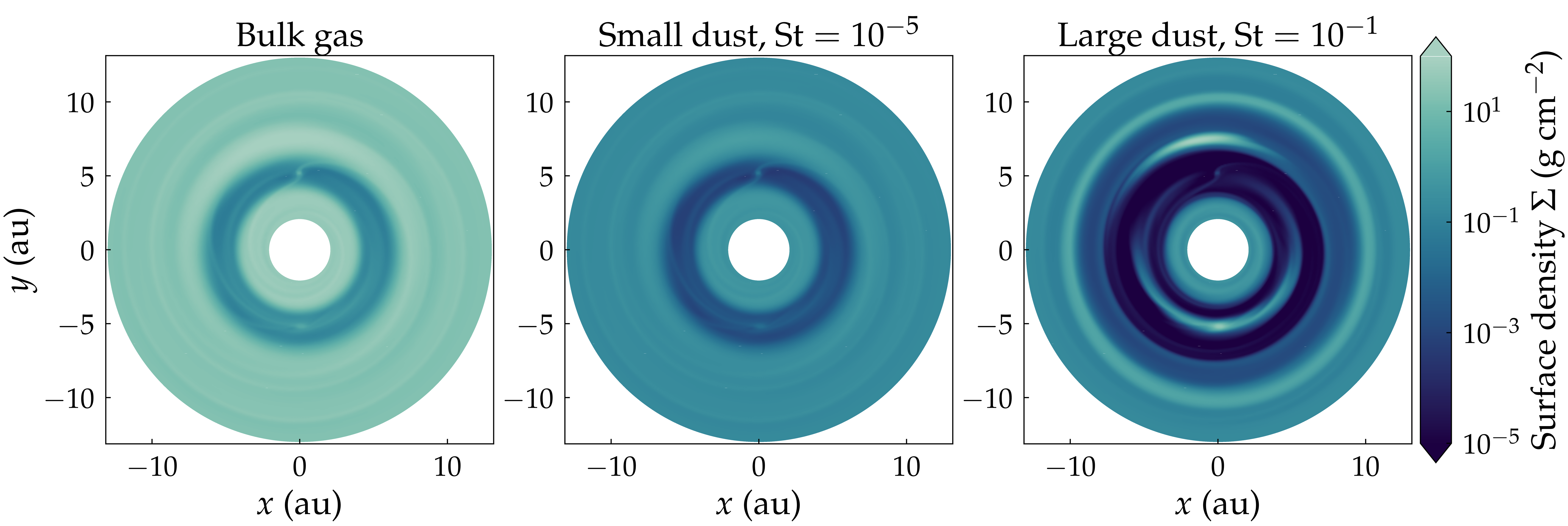
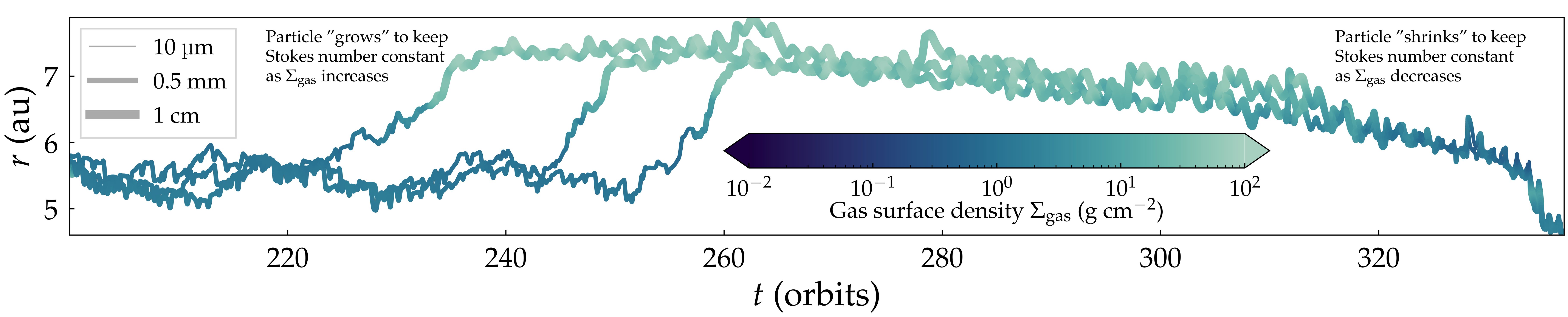
Motivation

$$\text{constant Stokes number} = \frac{(2\pi)^{1/2}\, a_{\rm gr}\rho_{\rm gr}}{\Sigma_{\rm gas}} \Rightarrow \text{varying grain size } a_{\rm gr}$$





- ▷ By default, FARGO3D (Benítez-Llambay & Masset, 2016; Benítez-Llambay et al., 2019) fixes a Stokes number for each population of solids, effectively simulating the dynamics of larger particles in denser regions
- ▷ A more careful treatment involves fixing a particle size, determining the drag regime (Stokes or Epstein) every time, and computing the local drag coefficient for each population at every grid cell and every timestep
- ▷ While more physically motivated, this calculation is significantly slower, and optimizing it for practical use is an ongoing effort

Results and Future Outlook

Our preliminary results indicate that fixing particle size, rather than Stokes number, may have a significant impact on the dynamics of larger particles near a gap carved out by a planet. In particular, **the frequency of particles crossing the gap, ultimately changing the composition of solids in the inner disk, may be affected.** Quantifying this effect requires a proper treatment of dust dynamics in the disk as the particles will move through regions of the disk with densities that vary by orders of magnitude. We are currently in the process of finalizing our modifications to FARGO3D. Stay tuned for a future publication!

References

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