Origins: From the Protosun to the First Steps of Life
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Pebble accretion onto planets in turbulent discs

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Abstract. Planets form in protoplanetary accretion discs around young protostars. These discs are driven by internal turbulence and the gas flow is not laminar but has stochastic components. For weakly ionised discs the turbulence can be generated purely hydrodynamically through the vertical shear instability (VSI). Embedded particles (dust/pebbles) experience a hydrodynamic drag and drift inward radially and are stirred up vertically by the turbulent motion of the disc. We study the accretion of particles onto a forming planet embedded in a VSI turbulent protoplanetary disc through a series of 3D hydrodynamical simulations for locally isothermal discs with embedded planets in the mass range from 5 to 100 Earth masses ($M_\oplus$).

Keywords. hydrodynamics; planetary systems: formation, protoplanetary disc

1. Particles in the disc

To calculate the dynamics of the disc we perform hydrodynamical simulations of a 3D section of a disc in spherical coordinates, using the PLUTO code. The disc is initially in an equilibrium state which is unstable to the VSI, generating turbulent motions for which we measure an effective $\alpha_\mathrm{d} = 5 \cdot 10^{-4}$. Particles of 10 different sizes (or stopping times) are embedded into the flow (10^5/bin) under the action of aerodynamic drag forces (SK16). These particles are stirred up by the VSI motions as displayed in Fig. 1, where we compare our results (crosses) to other models (circles).

2. Accretion of particles by embedded planets

In a second step we add planets of different masses to the simulations and monitor the accretion of the particles onto them. First we determined the *accretion efficiency* which is the number of accreted particles onto the planet divided by the number of particles that would otherwise drift across the location of the planet in an unperturbed disc, $P_{eff} = \dot{M}_\mathrm{acc}/\dot{M}_{\mathrm{d}rift}$, and second the *isolation mass*, which is the critical planet mass above which particle accretion is greatly reduced. Fig. 2 shows that the number of accreted particles is highest around unit stopping time, even though most of the particles drift past the planet in this size range. The isolation mass lies between 10 and 20 $M_\oplus$, above this planet mass the number of accreted particles around $\tau_\mathrm{s} \approx 1$ is essentially shut off. Due to the concentration of particles near the midplane (see Fig. 1) the results for the VSI and laminar disc models are similar in our case.

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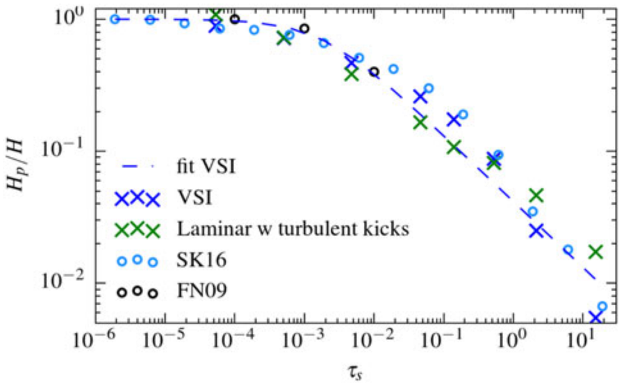

Figure 1. Vertical distribution (particle over gas scale height) of particles with different Stokes numbers τ_s. Compared are VSI and laminar (using α_d and stochastic particle kicks) models. Results of MHD (FN09) and previous VSI (SK16) runs are superimposed (adapted from PSK18).

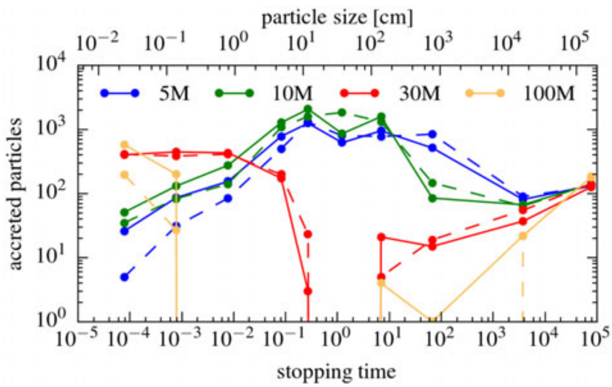

Figure 2. Accreted particles (integrated over 50 planetary orbits) as a function of the particle stopping time with the approximate size on the top x-axis (assuming a planet location at 5au). The VSI (solid line) and α-disc model (dashed line) are compared for different planet masses (in $M_\odot$). Adapted from PSK18.

3. Summary

The angular momentum transport generated by the VSI turbulence corresponds to $\alpha_d = 5 \cdot 10^{-4}$. The particle dynamics and accretion properties are similar for particles in the VSI turbulent disc and those in laminar case with stochastic kicks. For the small mass planets (i.e. $5 - 10M_\oplus$), well-coupled particles with $\tau_s = 1$, which have a size of about one meter at this planet location, we find an accretion efficiency $P_{\rm eff} \approx 1.6 - 3\%$, a result which compares well to LJ12. However, the fast inward drift for $\tau_s = 1$ particles makes them the most effective for rapid growth, leading to mass doubling times of about 20,000 yr provided there is a steady influx of pebbles. For masses between 10 and 30 $M_\oplus$ the core reaches the pebble isolation mass and the particles are trapped at the pressure maximum just outside of the planet, shutting off further particle accretion.

References

Fromang, S. & Nelson, R. P., 2009, *A&A*, 496, 597 (FN09)

Lambrechts, M. & Johansen, A., 2012, *A&A*, 572, A107 (LJ12)

Picogna, G., Stoll, M. H. R. & Kley, W., 2018, *A&A*, 616, A116 (PSK18)

Stoll, M.H.R. & Kley, W., 2016, *A&A*, 594, A57 (SK16)

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