Gas-particle Interaction and Planetesimal Formation

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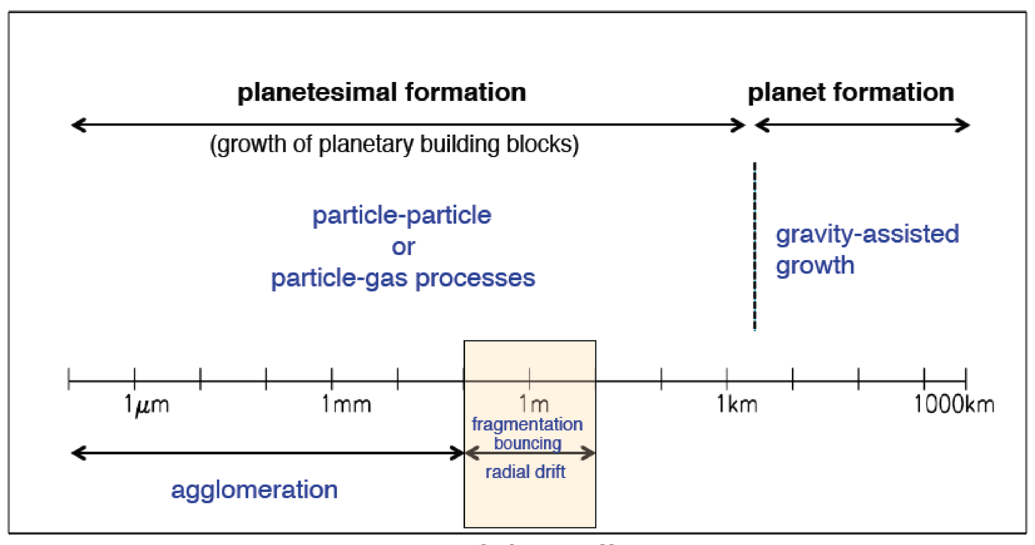
MAX-PLANCK-GESELLSCHAFT

Introduction

In circumstellar environments, fluid drag between the gas main disc and the dust sub-disc results in the accretion of disc solids, which would otherwise be available as material to form planets. This problem can be partially alleviated by collective dust-agglomerate drag effects whereby clustered particles assist one another in overcoming fluid drag, leading to a streaming instability (SI) and resulting in local density enhancements [1, 2, 3]. The SI can therefore potentially assist macroscopic bodies in overcoming growth barriers [4, 5] in the ∼1m regime *en route* to planetesimal formation. We study the vertical settling of spherical dust particles in a low-pressure laboratory flow, in order to check the expectation that SI will develop. We supplement the experiments with simulations using a two-fluid approach and conditions that reflect the laboratory setup.

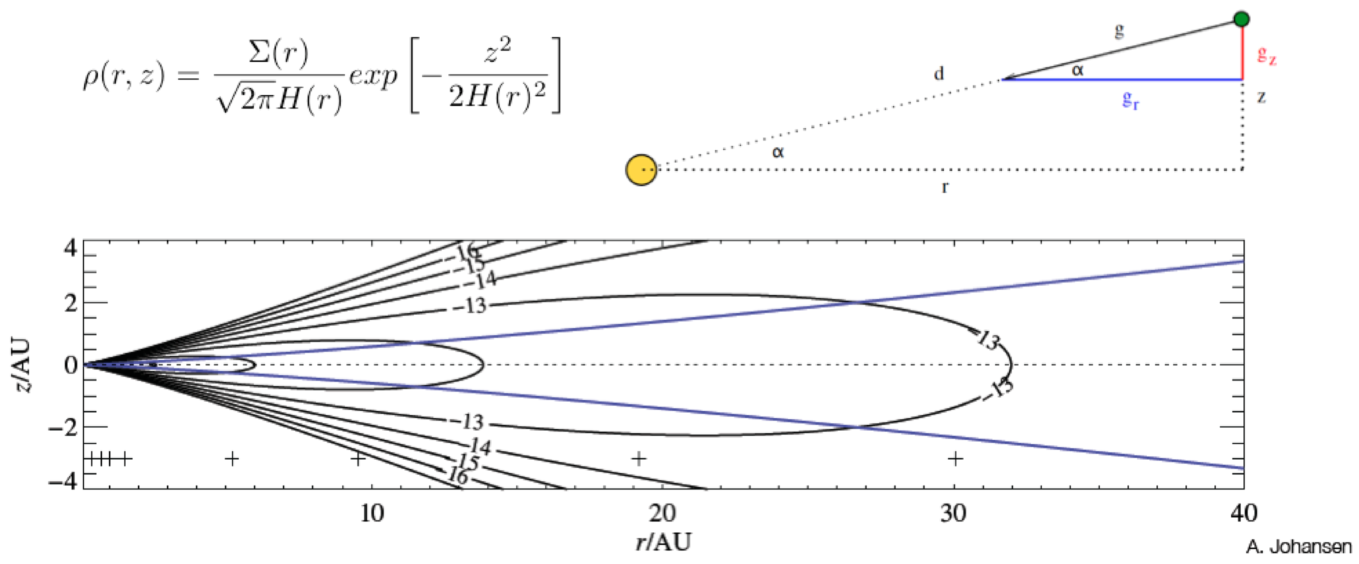
Planetary Growth & the SI



particle radius

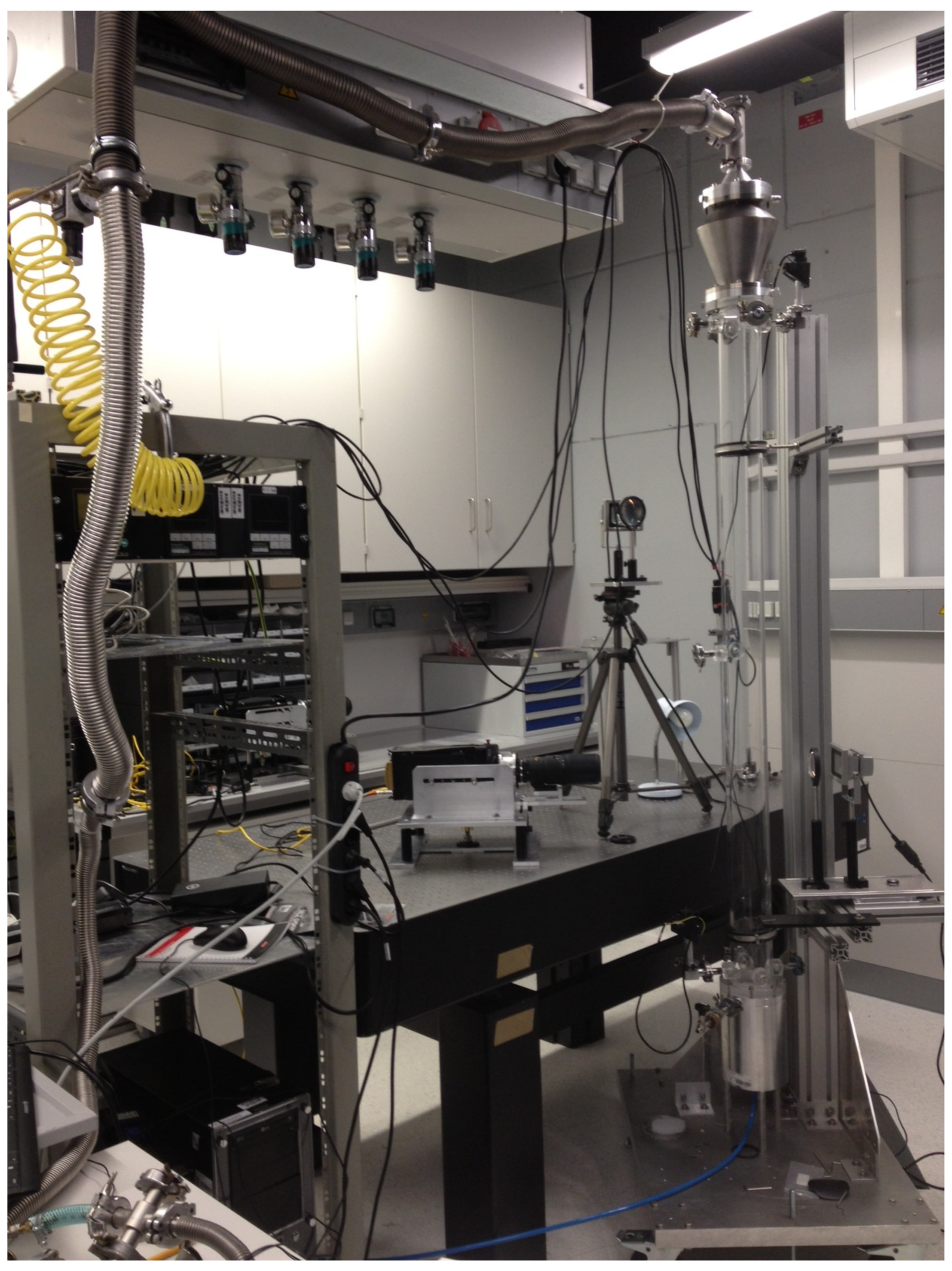
Transport and Settling of Disc Solids

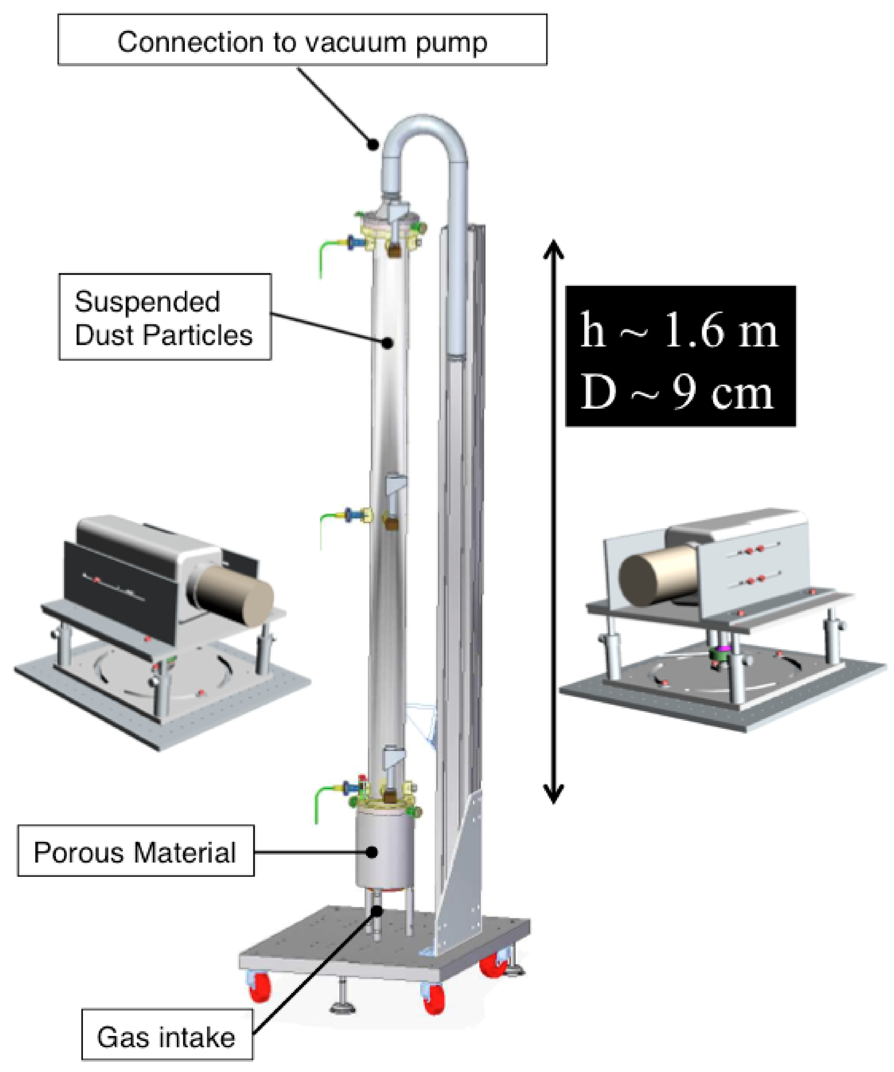
$$\rho(r,z) = \frac{\Sigma(r)}{\sqrt{2\pi}H(r)} exp\left[-\frac{z^2}{2H(r)^2}\right]$$



In the classical view of planetestmal formation, solids must settle near the disc mid plane in order to enhance the density of solids such that a gravitational instability can occur [6]. Our studies of vertical settling due to dust-gas fluid instabilities may have implications for enhancing vertical solid sedimentation in protostellar discs, in addition to informing the more commonly discussed case of the SI operating in the radial direction [7, 8].

Göttingen Dilute Gas Stream Facility

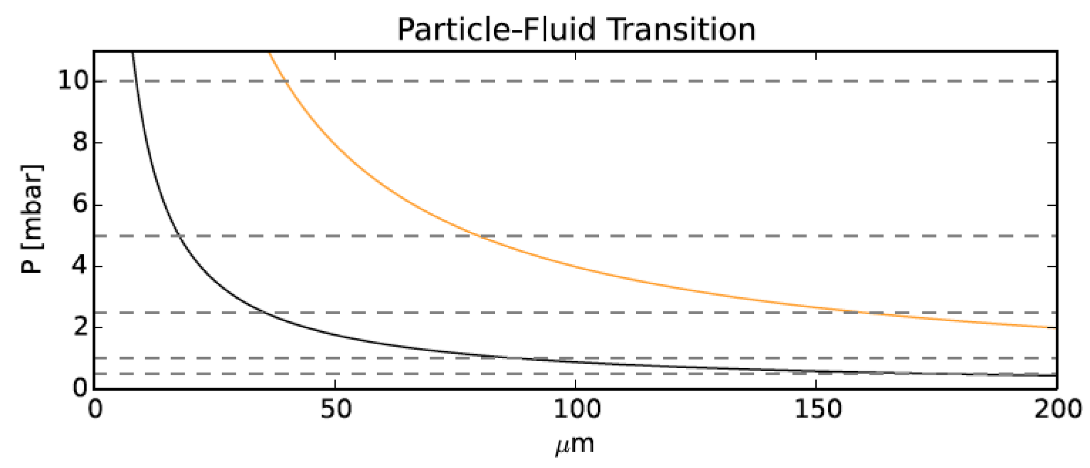




Drag Regimes

$$T_f = \frac{m|\vec{v}|}{F_D} \qquad F_D = \begin{cases} 3\pi d_p \eta u_{rel} & \text{if } d_p \gtrsim \frac{9}{2}\lambda \\ \frac{\pi}{3}\rho d_p^2 v_{therm} u_{rel} & \text{if } d_p \lesssim \frac{9}{2}\lambda \end{cases}$$

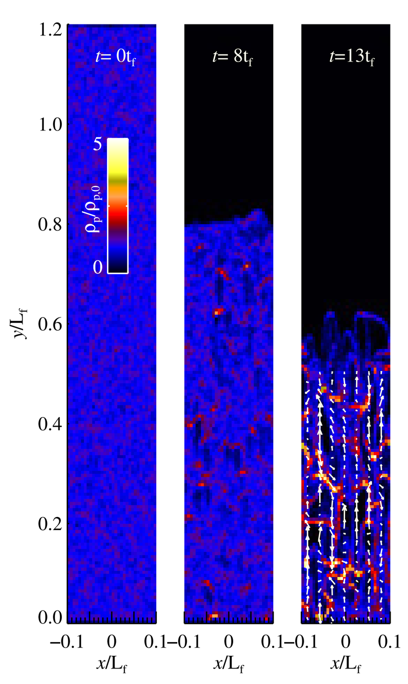
$$\frac{9\lambda}{2} = 6.4\ \text{cm}\left(\frac{r}{\text{AU}}\right)^{2.75} \quad \text{(MMSN)}$$



Summary and Outlook

The experiments consist of a laminar, particle-laden flow, analogous to the quiescent mid plane around 1-10 AU or inter-eddy regions in protoplanetary discs. 2-D imaging shows evidence for small-scale, local density enhancements, by ∼5, for particles coupled to the flow. Larger numbers of statistics must be collected to verify this behaviour and 3-D Lagrangian particle tracking [9] will be used to assess whether any such density enhancements are correlated with the relative gas-particle velocities.

Simulations: Instability Growth



Dust

$$\frac{\partial \rho_p}{\partial t} + \nabla \cdot (\rho_p \vec{v}_p) = 0$$

$$\frac{D\vec{v}_p}{Dt} = -g - \frac{1}{T_f}(\vec{v}_p - \vec{v}_g)$$

Gas

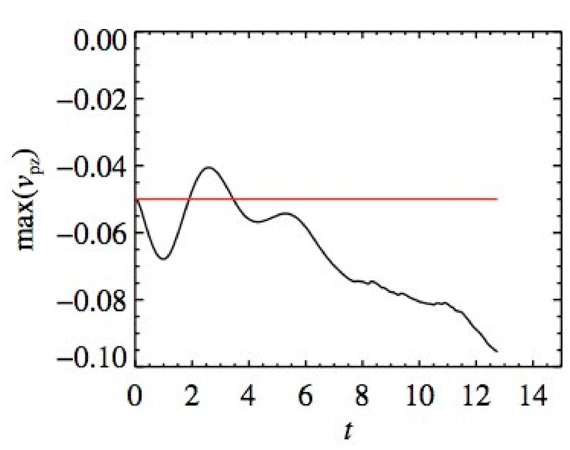
$$\nabla \cdot \vec{v}_g = 0$$

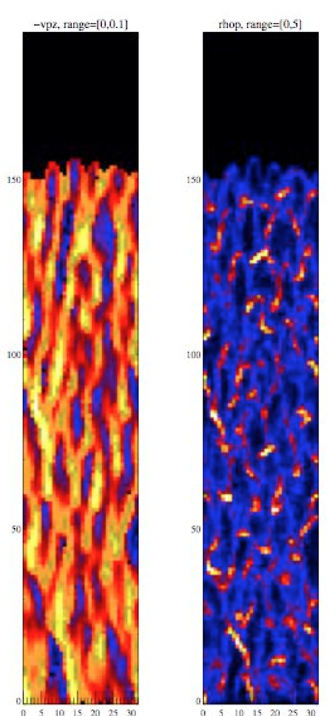
$$\frac{D\vec{v}_g}{Dt} = \epsilon g - \frac{\epsilon}{T_f}(\vec{v}_p - \vec{v}_g)$$

Units

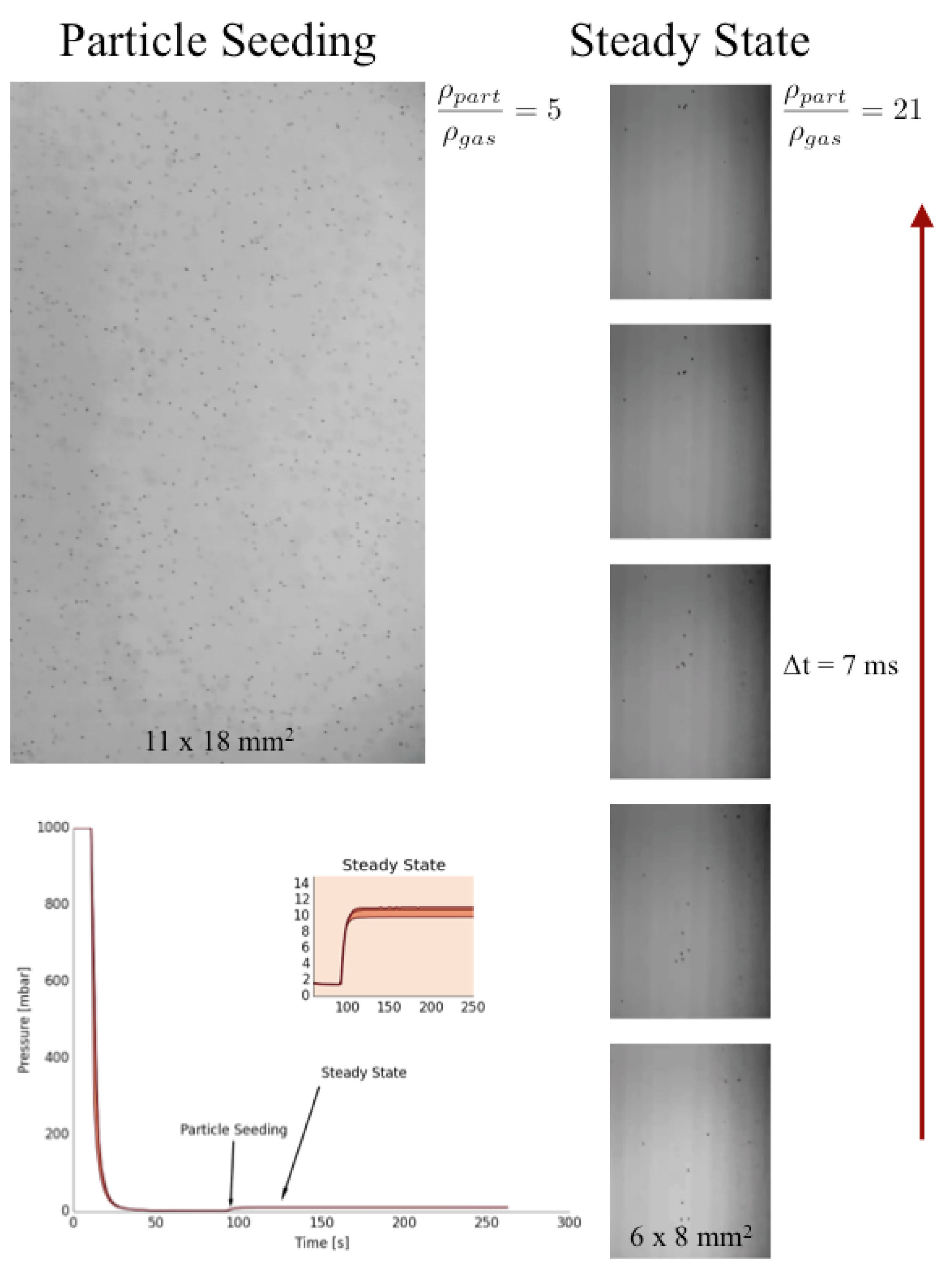
$$t = T_f$$
$$v = T_f g$$
$$l = T_f^2 g$$

Simulations: Density-Velocity Correlation





Experimental Data



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