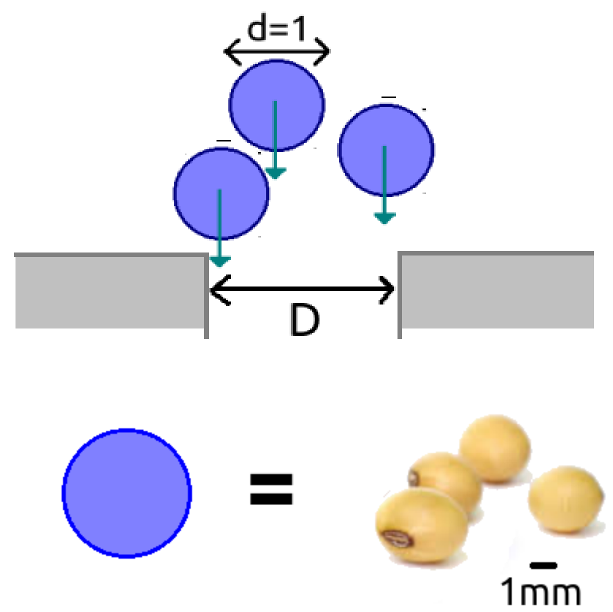
Granular flows through an orifice:
Can gentle vibrations prevent clogging?

Alexandre NICOLAS (CNRS / Univ. Lyon 1), Iker ZURIGUEL (Univ. Navarra, Pamplona), Ángel GARCIMARTÍN (Univ. Navarra, Pamplona)

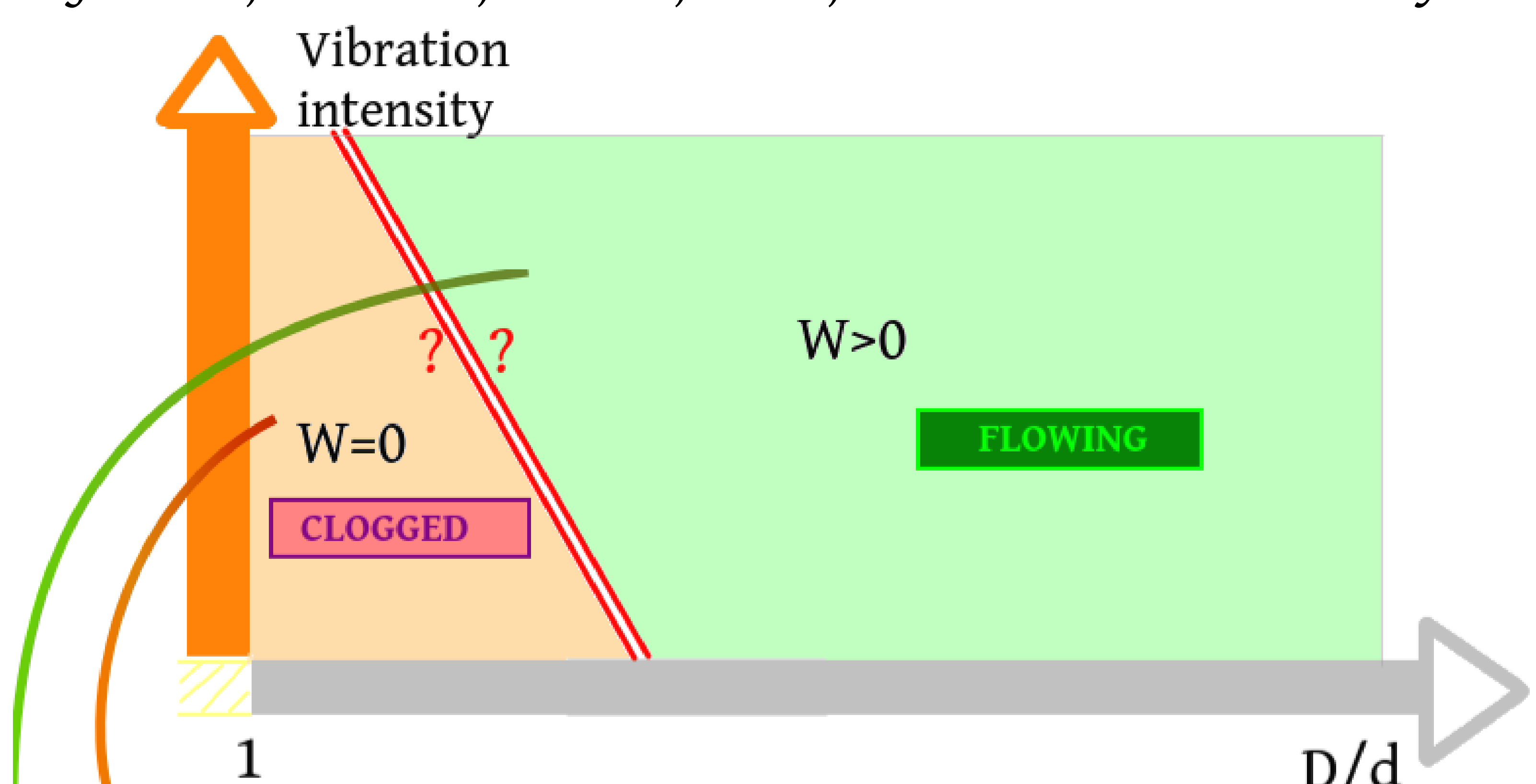
Context



Silos and narrow outlets may undergo clogging, because of the formation of stable arches (2D) or vaults (3D) of grains blocking the orifice.
These clogs can be destroyed by applying vertical vibrations to the device (Lozano et al. 2015), but do not disappear instantly. Instead, they survive for a finite lifetime, whose distribution was experimentally found to be particularly heavy-tailed (Zuriguel et al. 2014).
Can these features be rationalised within a generic theoretical framework ?

Puzzling questions

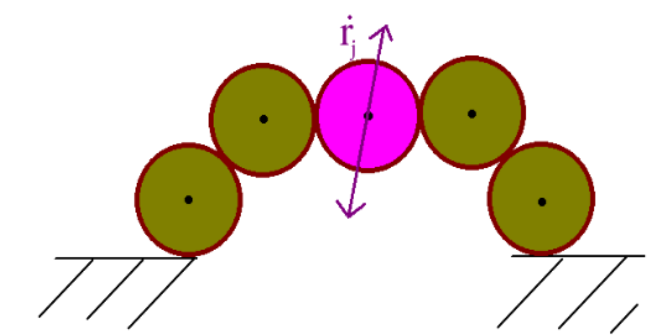
Consider the following tentative out-of-equilibrium phase diagram for the granular flow W as a function of the orifice size and vibration intensity Γ.



1. *Any clog will finally be destroyed by vibrations. So how can there still be a clogged regime ?*
2. ***Can (gentle) shaking actually restore the flow in a system that is otherwise prone to clogging ?***

Our model

Newton's equation for 'weak grain' on the arch



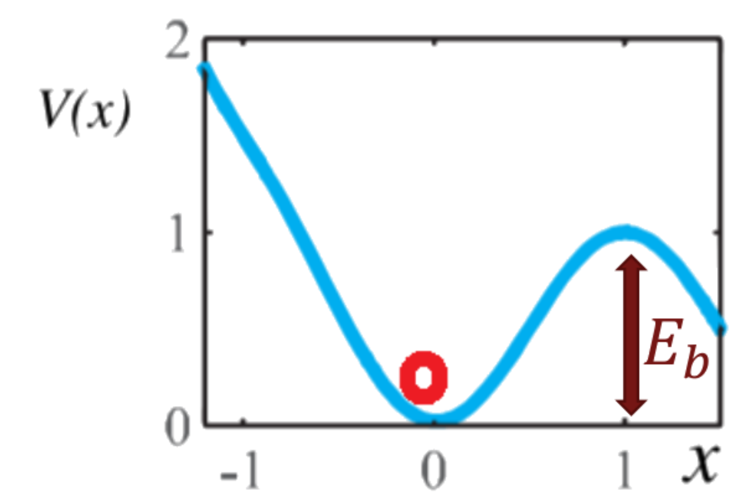
$$\ddot{\boldsymbol{r}}_j = -\frac{\partial}{\partial \boldsymbol{r}_j} V(\boldsymbol{r}_1, \ldots, \boldsymbol{r}_N) + \boldsymbol{g} + \underbrace{\boldsymbol{f}_j}_{\text{friction}} + \underbrace{\xi(t)}_{\text{vibrations}}$$

with $\langle \xi(t) \rangle = 0$ and $\langle \xi(t)\xi(t') \rangle \propto \Gamma^2 \delta(t-t')$

Assuming viscous friction $\boldsymbol{f}_j \equiv -\gamma \dot{x}$, for simplicity,

Looks similar to Langevin equation for a Brownian particle,

subjected to vibrational temperature $T \equiv \frac{\Gamma^2}{\gamma}$ (← acceleration, ← friction)



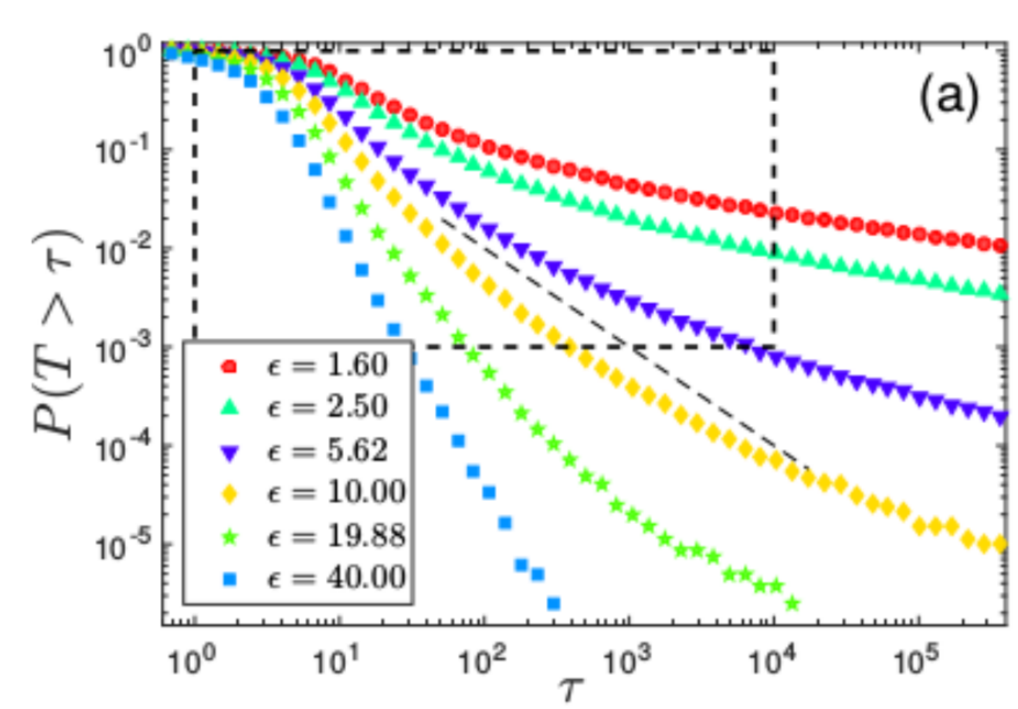
: arch stability

Kramers' escape time $\sim e^{\frac{E_b}{T}}$

Our results

$$P(T > \tilde{\tau}) \approx P\left[E_b(T) > E_b(\tilde{\tau})\right] \approx e^{-(\epsilon \ln \tilde{\tau})^{1/2}}$$

$$\epsilon \equiv \frac{\Gamma^2}{\gamma E_b^\star}$$



- Heavier than power-law decay
- Flatter and flatter as vibrational temperature decreases
- Despite its simplicity, the model affords semi-quantitative agreement with the experimental data

(Nicolas et al., 2018)

The native arch stabilities are heterogeneous; this disorder is amplified by the Kramers' process

For the full story, see : Lozano et al., *Physical Review E* (2015) ; Zuriguel et al., *Scientific Reports* (2014) ; Nicolas et al., *Physical Review Letters* (2018)