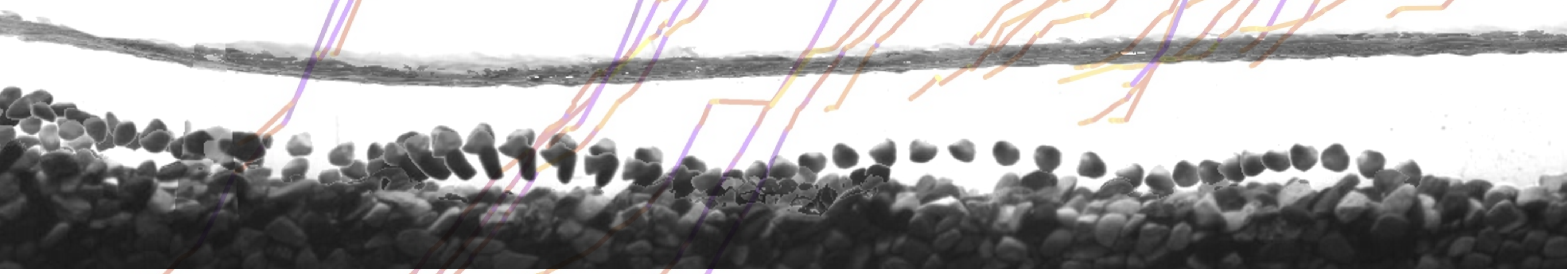
Bed load dynamics at the onset of motion



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Introduction

Bed load: transport of heavy sediment material by a fluid along an erodible bed.

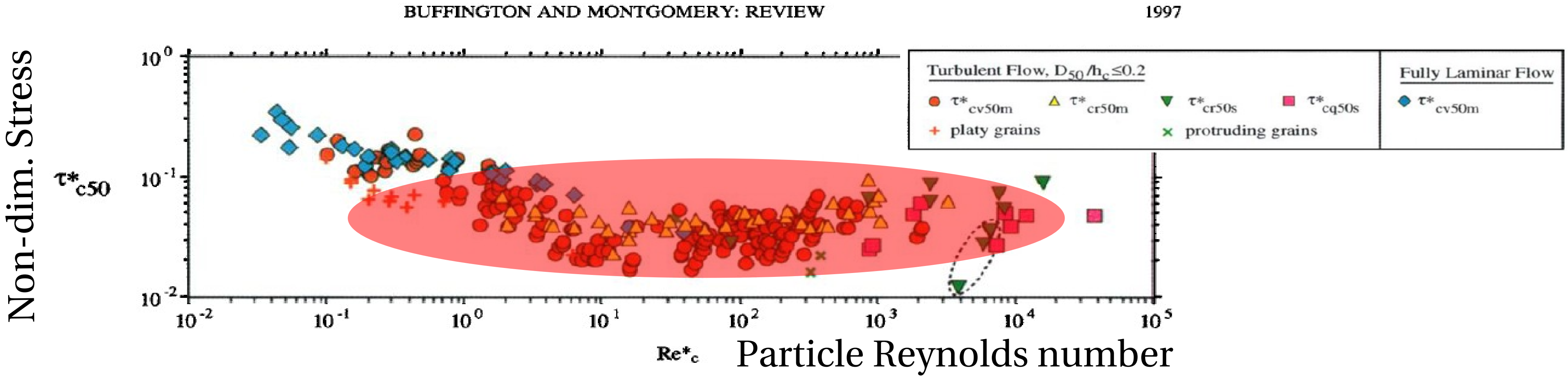
→ Complexity

- Granular media
- Turbulent Flow

- Naturally instable

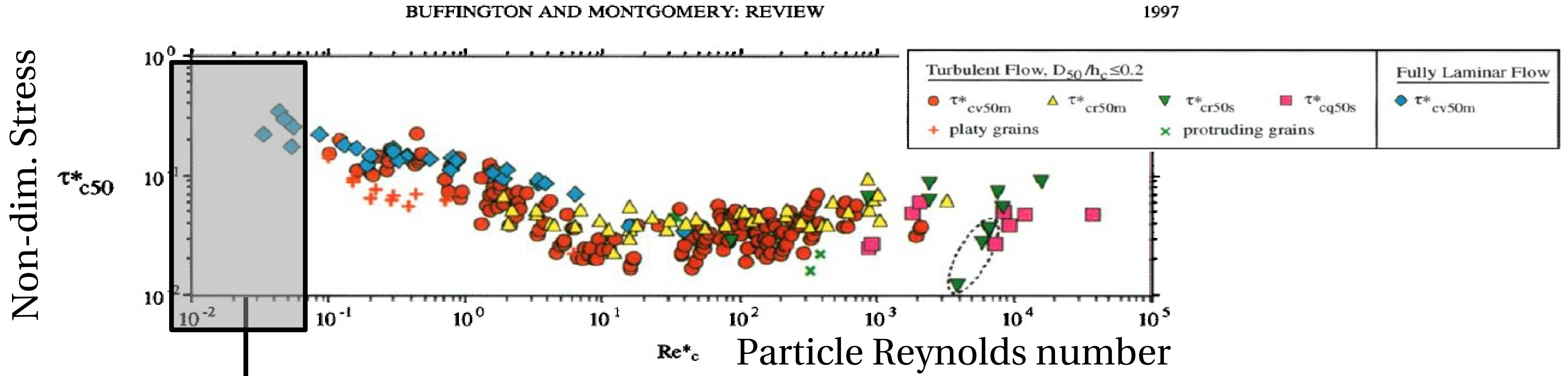
→ At the onset of motion, the complexity is increased

Introduction

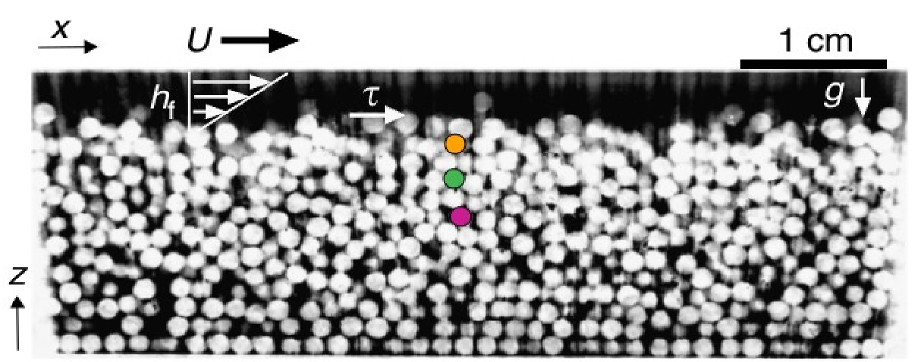


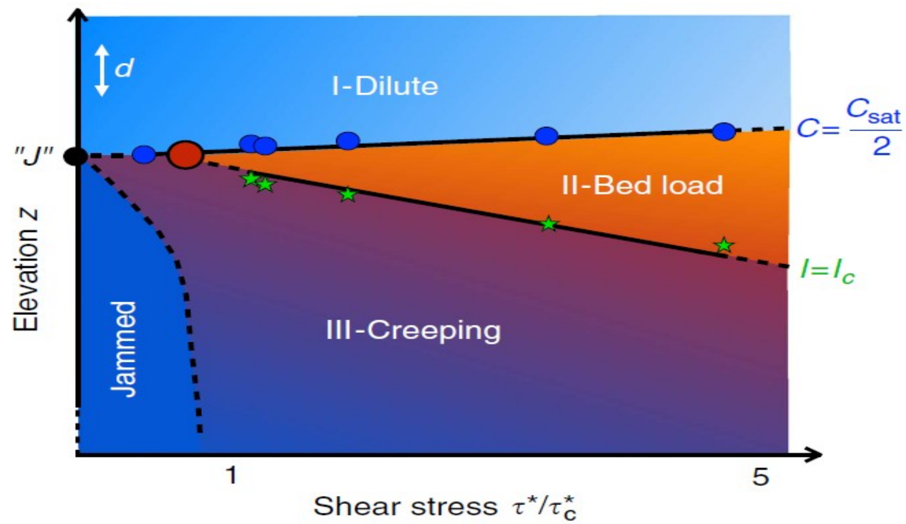
→ Large dispersion on the value of the stress « threshold» of particle motion

Introduction



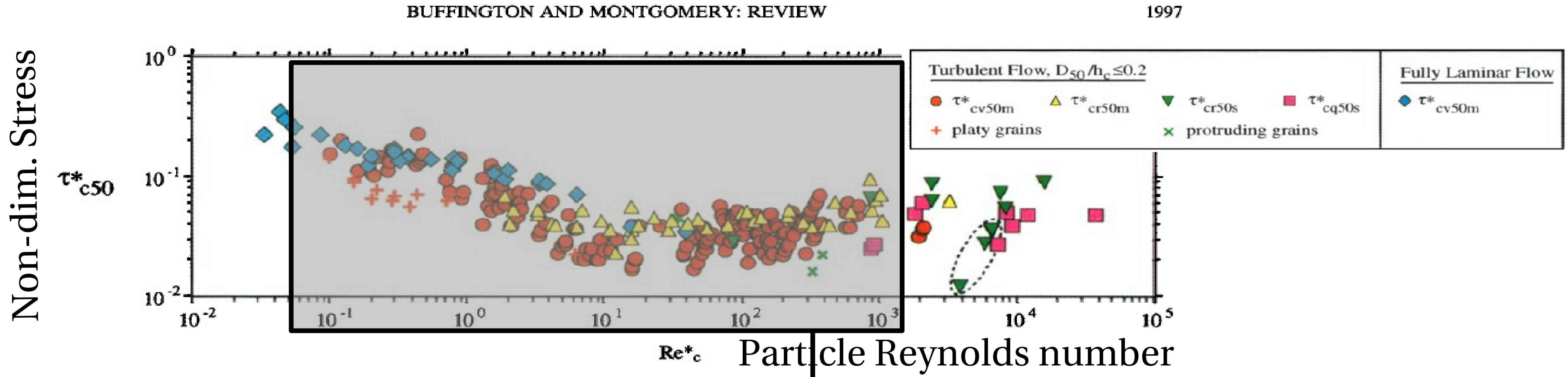
Houssais et al., *Onset of sediment transport is a continuous transition driven by fluid shear and granular creep.* Nature communications, **2015**



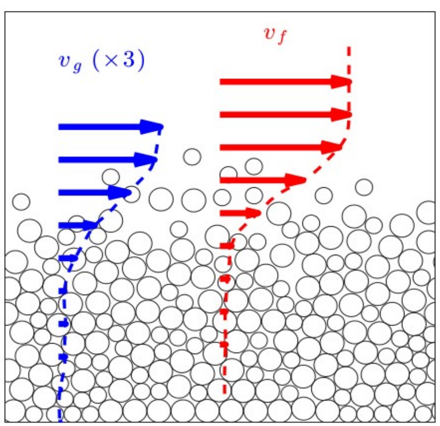


Laminar flow (*Re*<3) ;
Small plastic beads $St = Re_p \rho_p / \rho_f \sim 10^{-2}$

Introduction

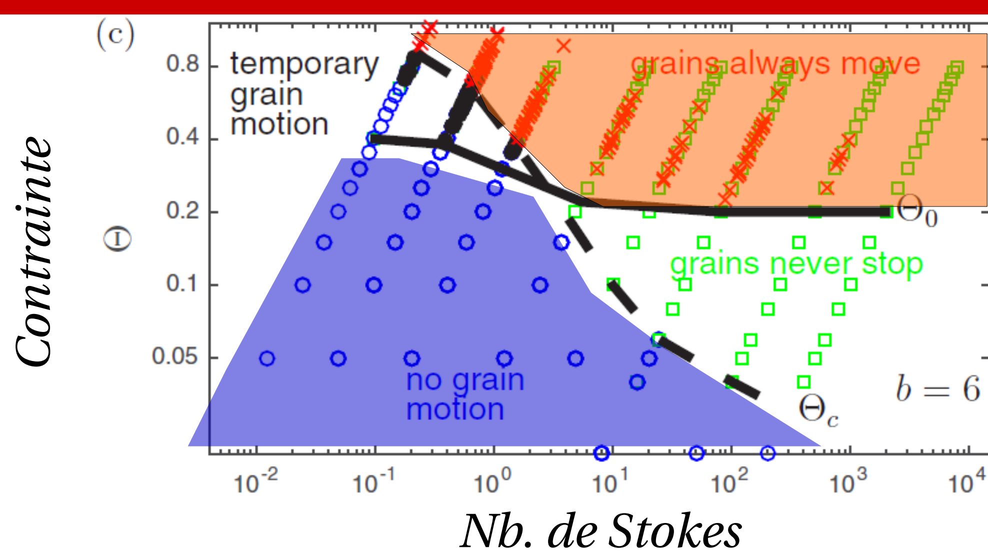


Clark et al., *Onset and cessation of motion in hydrodynamically sheared granular beds*. Physical review E, **2015**

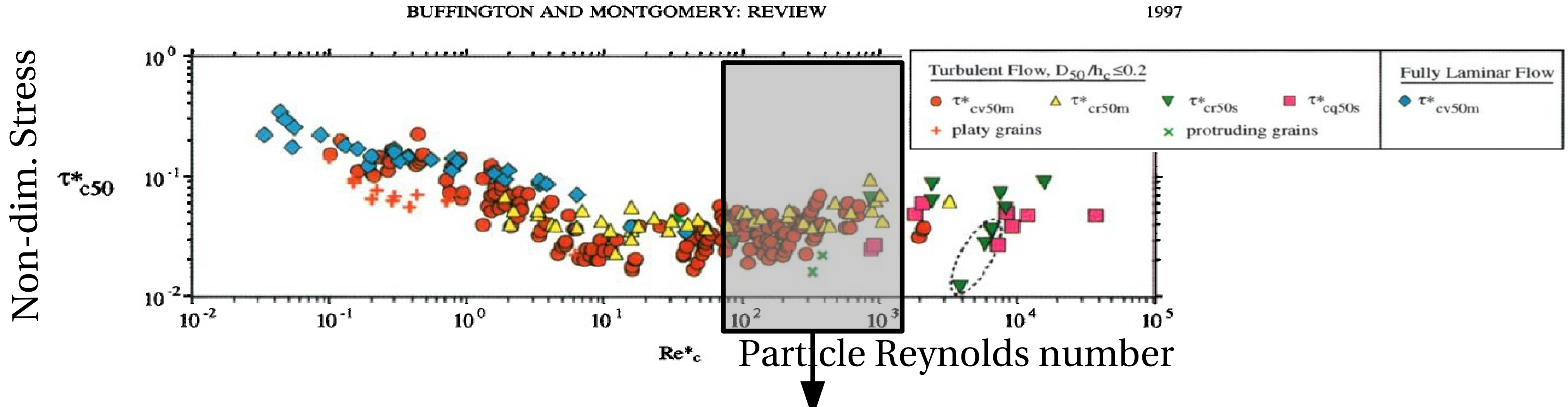


Simulation DEM

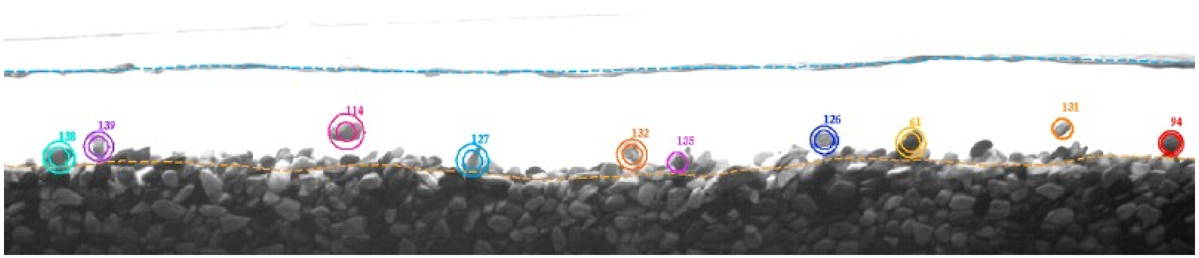
+ *model drag, St ~ 10^{-1} -10^{3}*



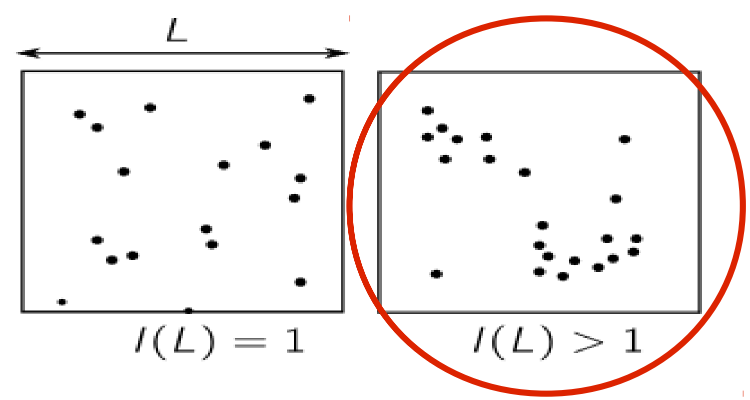
Introduction



Heyman et al., *Spatial correlations in bed load transport : Evidence, importance, and modeling*. Journal of Geophysical Research : Earth Surface, **2014**



Turbulent flow (*Re*>10^4)
Large grains, $St = Re_p \rho_p / \rho_f \sim 10^3$



Clustering of particles

Motivations

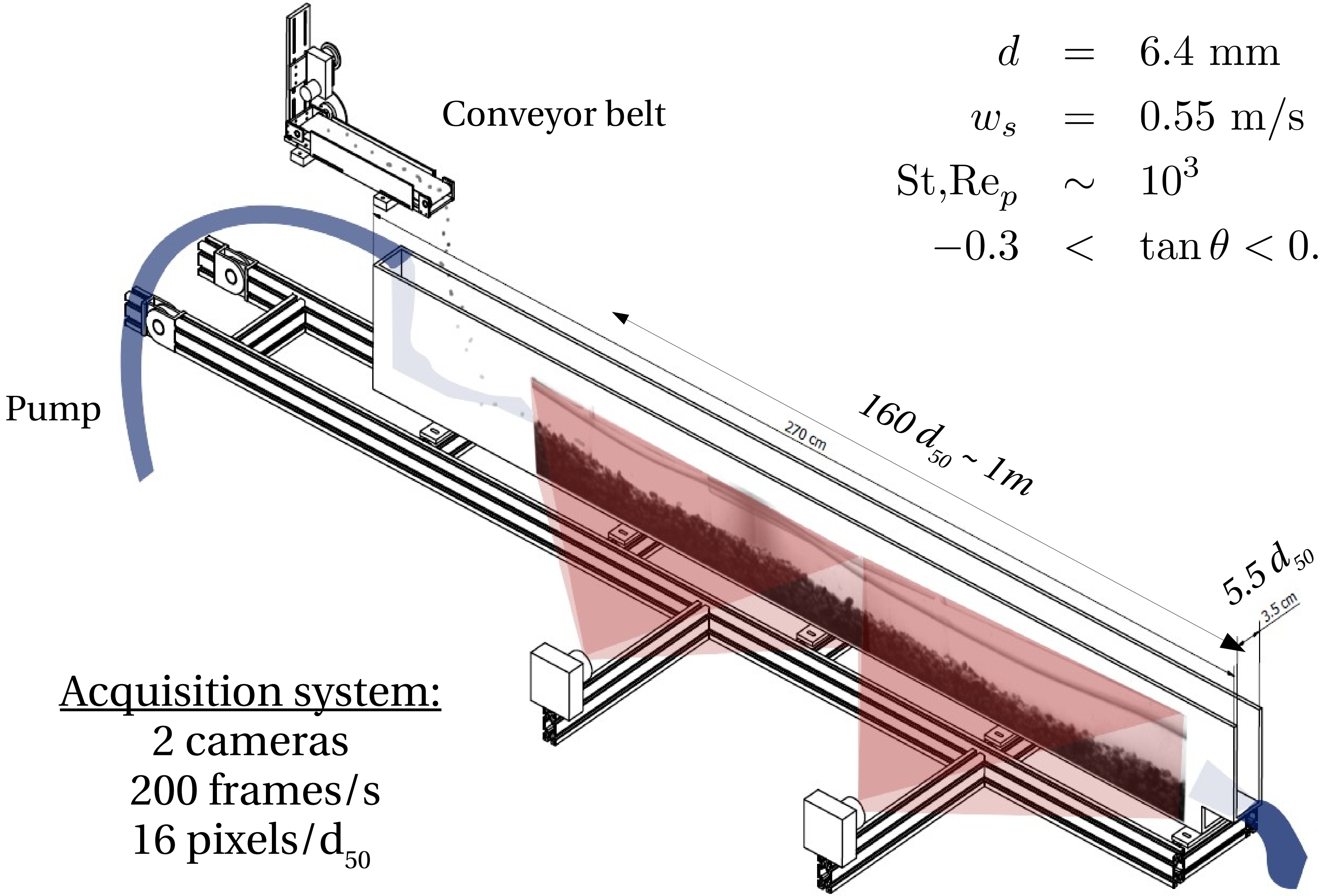
What are the dominant transport dynamics close to the motion threshold ?

→ in the case of high Stokes number

Methods

- Measurements at the grain scales (spatially and temporally)
- Large data-sets (since transport is intermittent)

Experimental setup



$$
\begin{aligned}
d &= 6.4 \text{ mm} \\
w_s &= 0.55 \text{ m/s} \\
\text{St},\text{Re}_p &\sim 10^3 \\
-0.3 &< \tan\theta < 0.1
\end{aligned}
$$

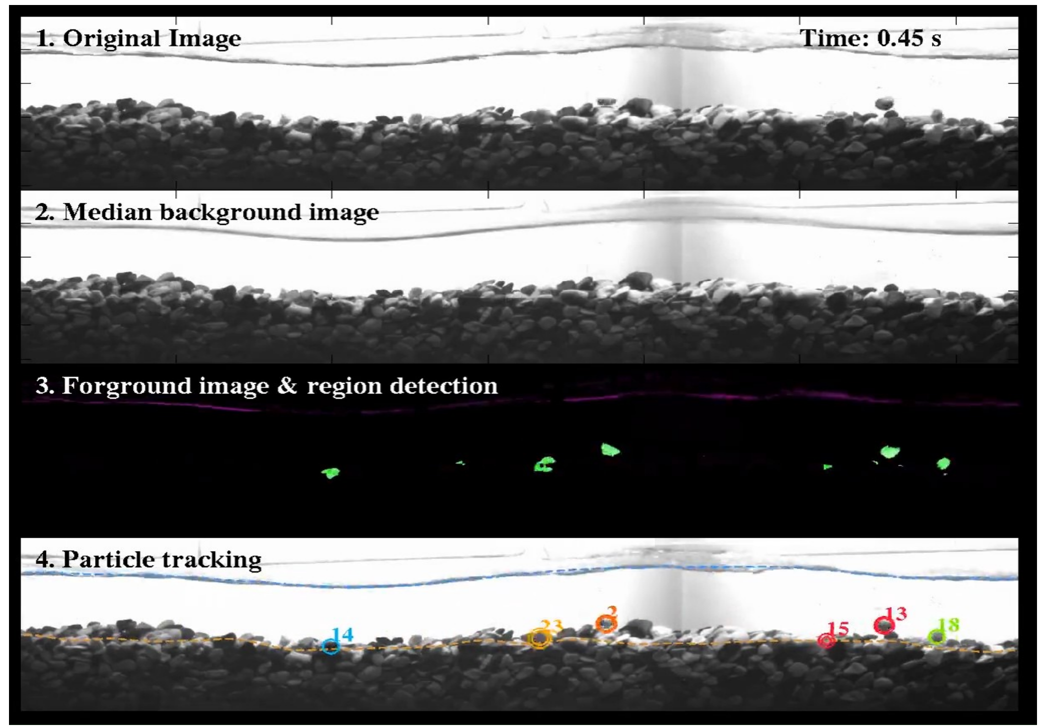
Acquisition system:
2 cameras
200 frames/s
16 pixels/d_{50}

Méthodes expérimentales

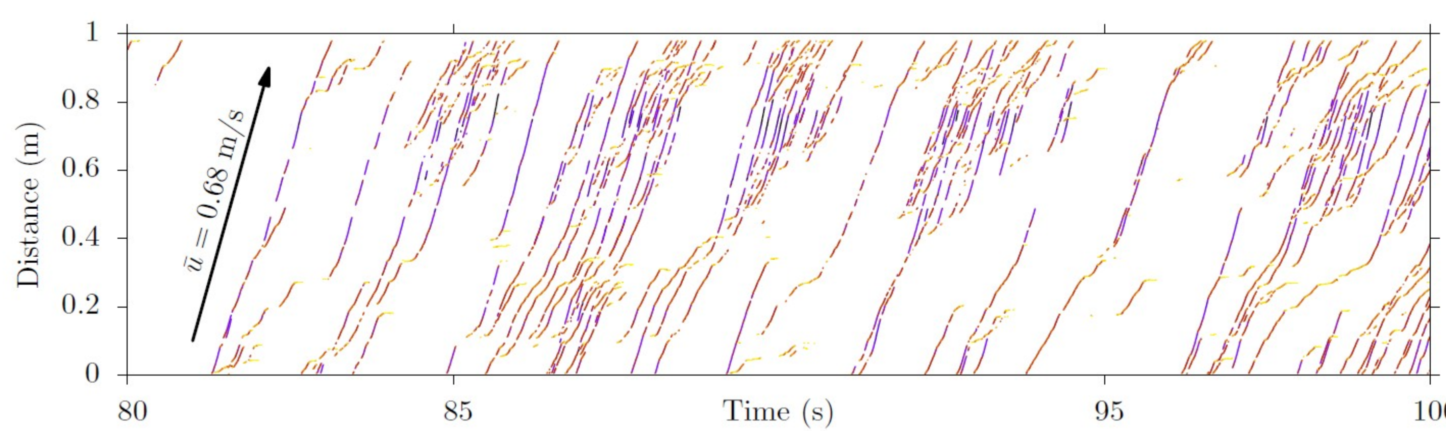
Automated
Particle Tracking Algorithm

(Available at
https://goo.gl/p4GbsR)

~ 40 sequences of 150 s
at 200 fps
(~1.2 million images)



Particle trajectories in space-time plane

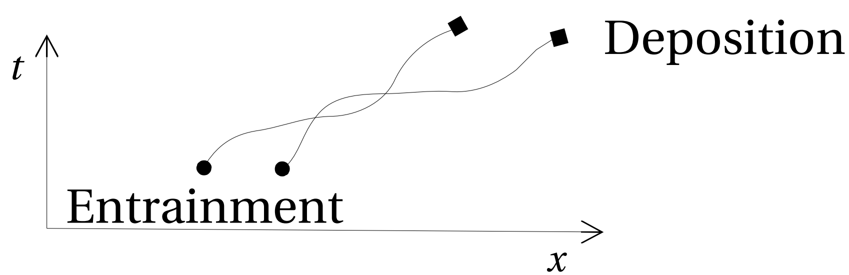


Variables

$$\text{Position} \quad \vec{x}_p(t)$$

$$\text{Speed} \quad \vec{v}_p(t) = \frac{\vec{x}_p(t+1) - \vec{x}_p(t-1)}{2\Delta t},$$

$$\text{Acceleration} \quad \vec{a}_p(t) = \frac{\vec{x}_p(t+1) + \vec{x}_p(t-1) - 2\vec{x}_p(t)}{\Delta t^2},$$



...and other variables : - water depth-average velocity and shear velocity
- water depth
- bed elevation and slope ...

On-board camera following a bedload particle

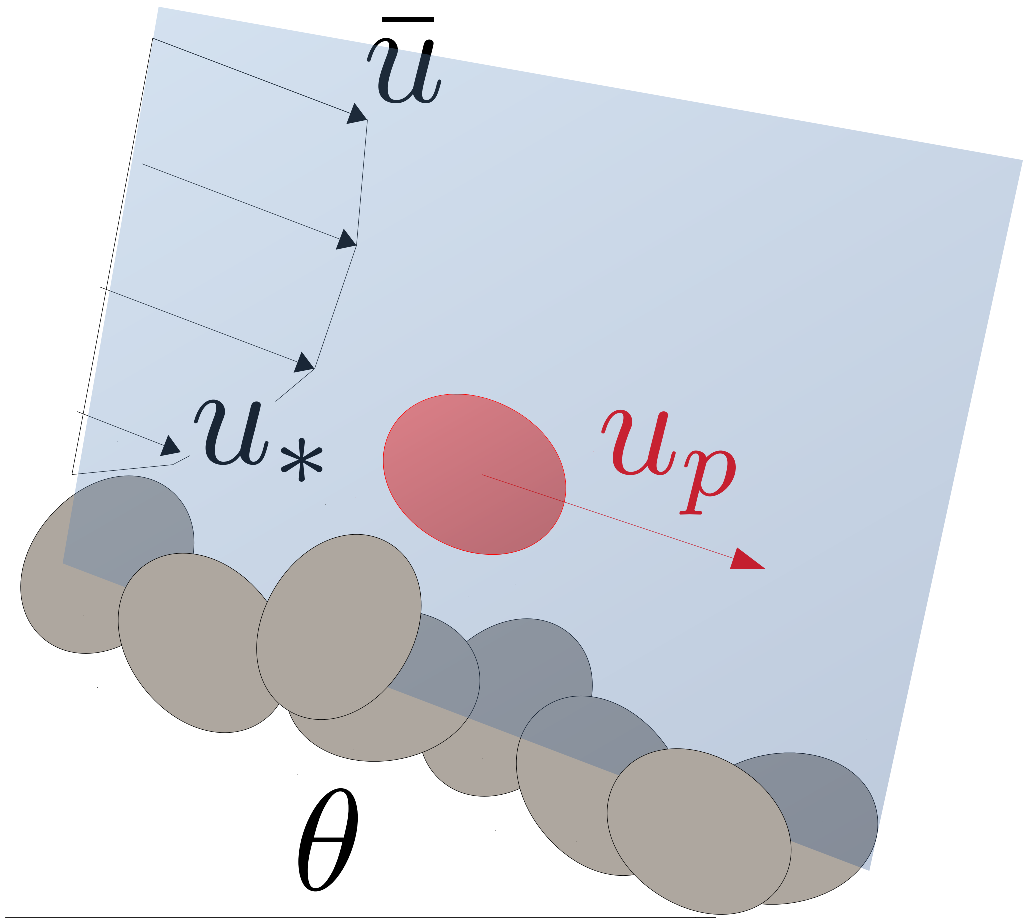
$||\vec{u}|| = 0.83$ m.s^{-1} $||\vec{a}|| = 4.69$ m.s^{-2} $||\omega|| = 2.01$ tr.s^{-}

Results

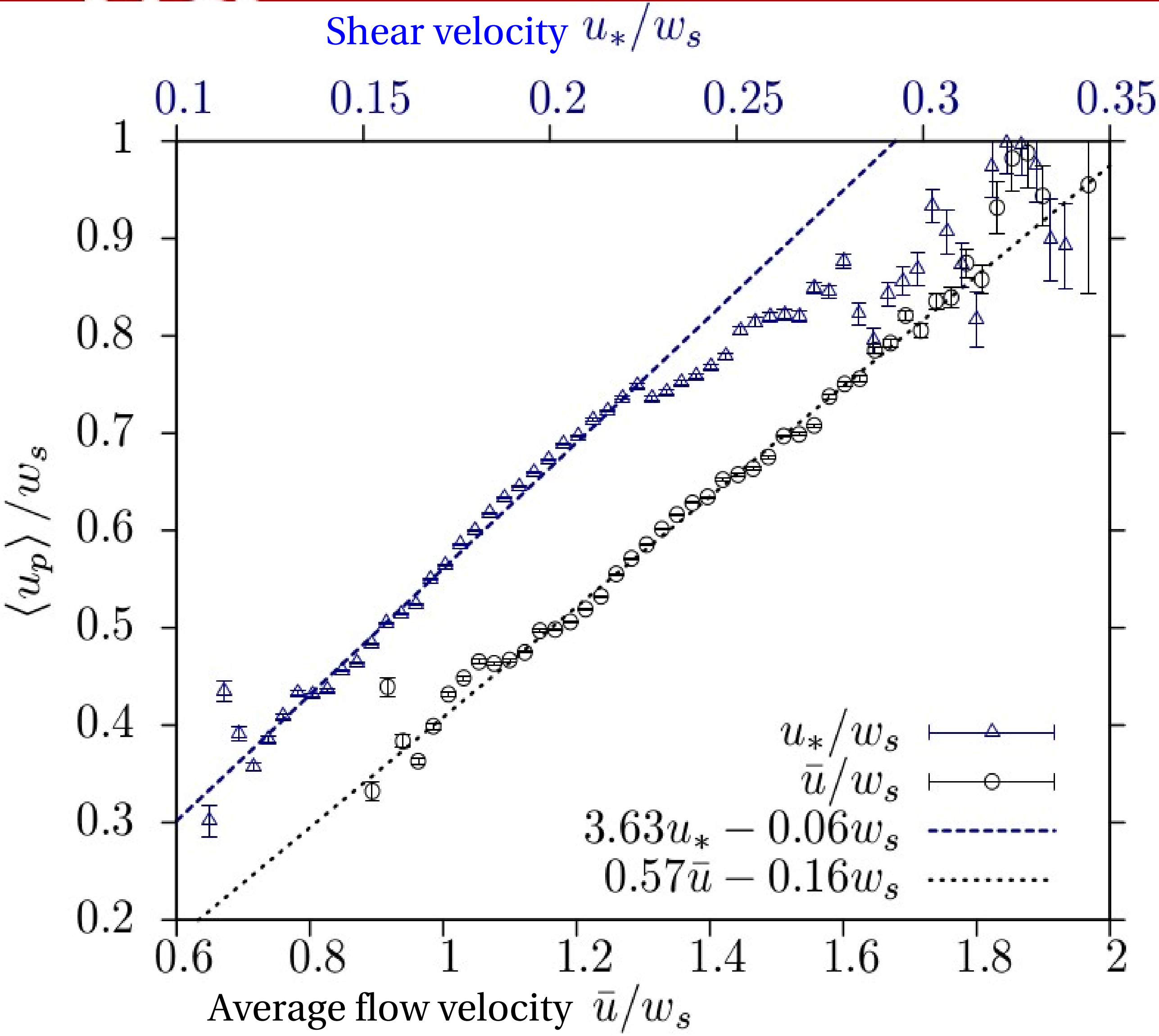
1) Kinematics

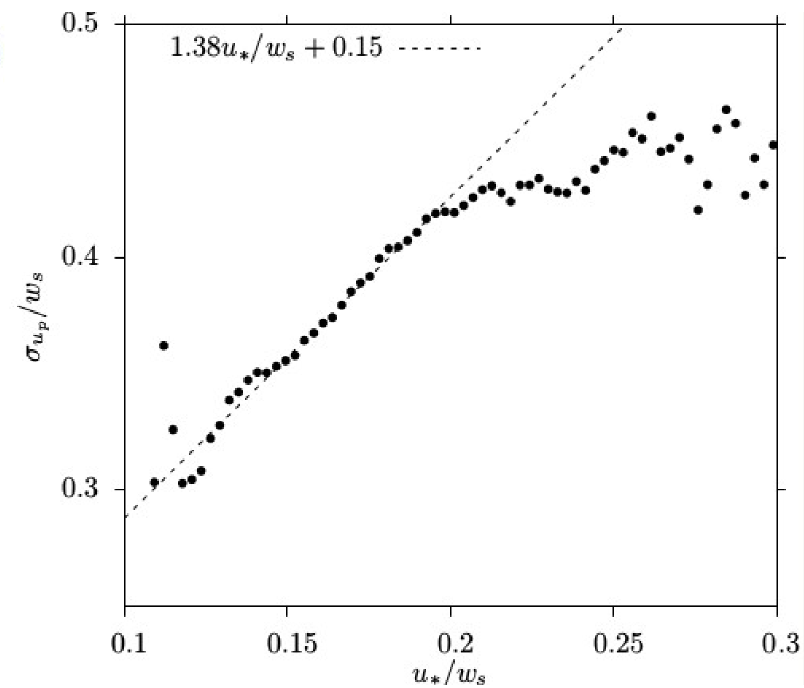
2) Deposition

Results / Particle velocity



Results / Particle velocity





$\langle u_p \rangle$: Average particle velocity

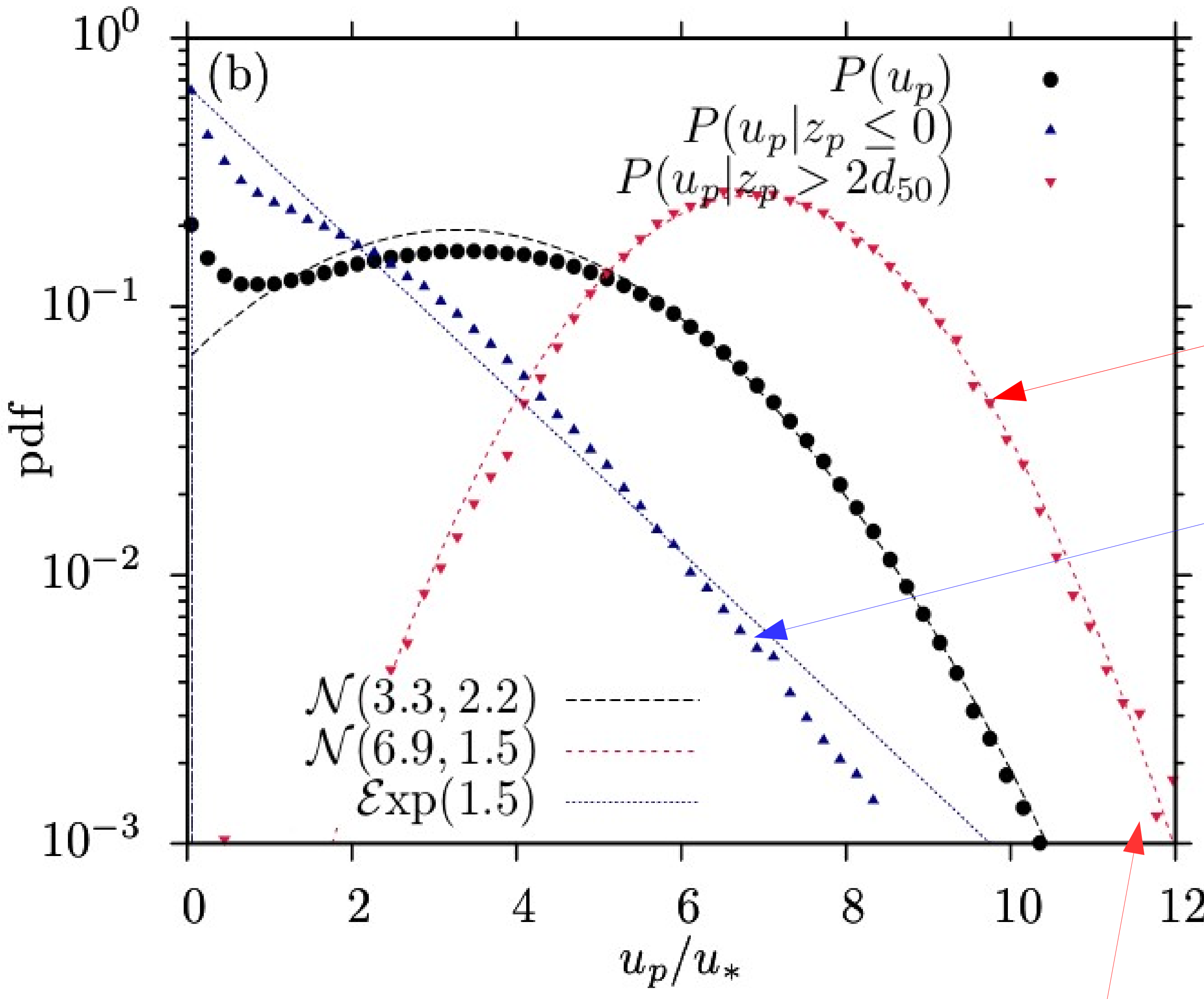
σ_{u_p} : Standard deviation

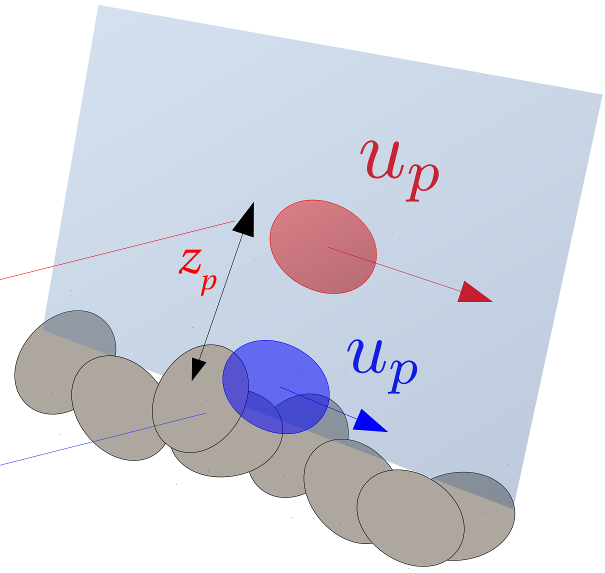
w_s : Settling velocity

$\bar{u}$: Average flow velocity

u_* : Shear velocity

Results / Particle velocity





Gaussian-distributed particle velocities

$\langle u_p \rangle$: Average particle velocity

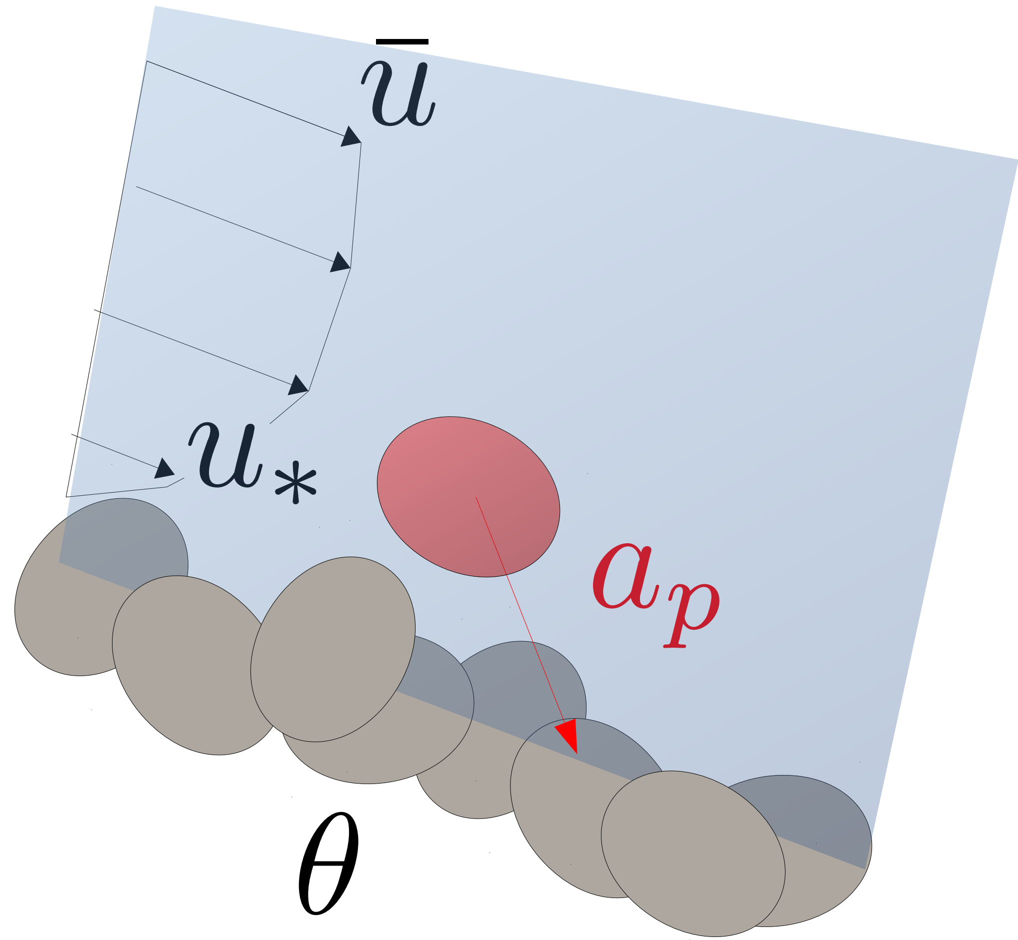
σ_{u_p} : Standard deviation

w_s : Settling velocity

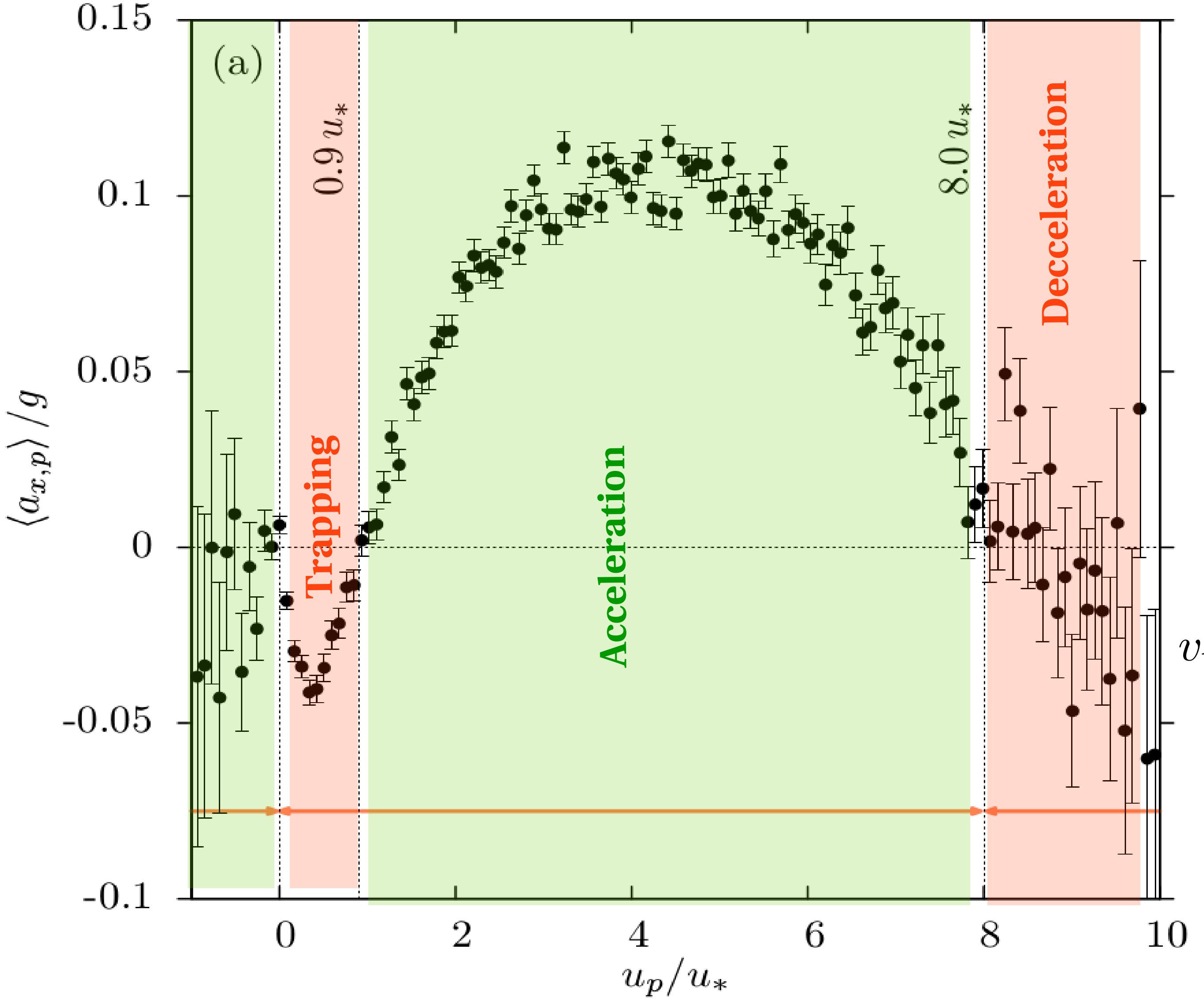
$\bar{u}$: Average flow velocity

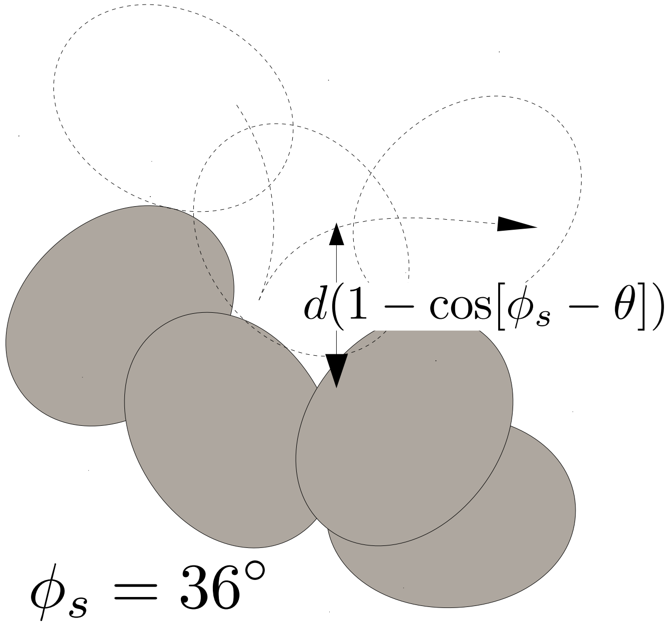
u_* : Shear velocity

Results / Particle acceleration



Résultats / Accélérations





$$\phi_s = 36^\circ$$

$$
\begin{aligned}
v_{\text{trap}} &\propto \sqrt{2gd(1 - \cos[\phi_s - \theta])} \\
&\approx 0.14 \text{ m/s} \\
&\approx u_*
\end{aligned}
$$

Résultats / Accélérations

PHYSICAL REVIEW E VOLUME 62, NUMBER 6 DECEMBER 2000

Dynamics of a grain on a sandpile model

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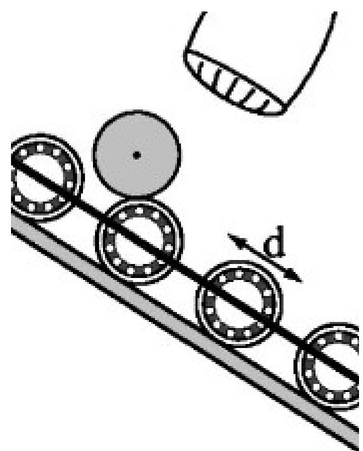
(Received 5 June 2000)

The dynamics of a macroscopic grain rolling on an inclined plane composed of fixed identical
investigated both experimentally and theoretically. As real sand, the system exhibits an hysteretic



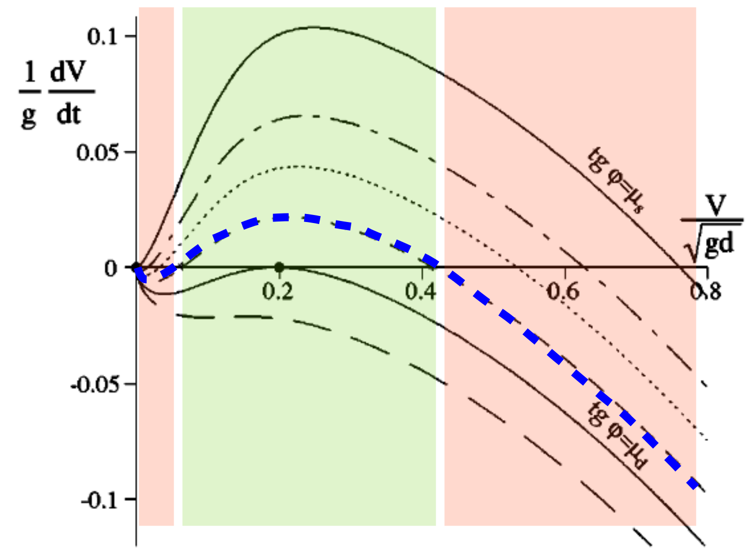
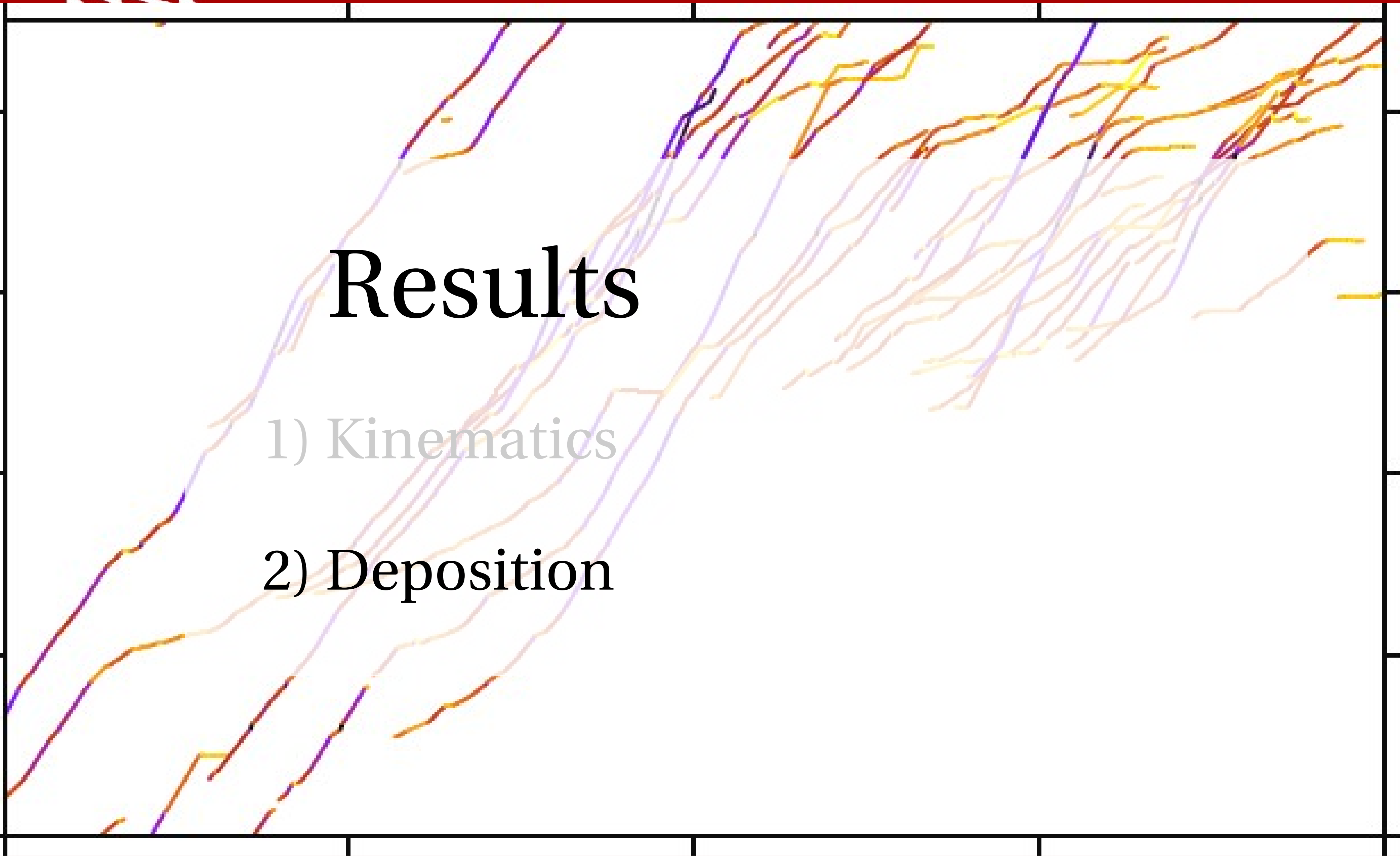


FIG. 12. Continuous model of the force globally acting on the roller. The force is plotted as a function of velocity for different angles: $\varphi=4°$ (long-dashed line), $\varphi=\varphi_d$ (solid line), $\varphi=14°$ (dashed line), $\varphi=19°$ (dotted line), $\varphi=24°$ (dotted-dashed line), and $\varphi=\varphi_s$ (solid line).

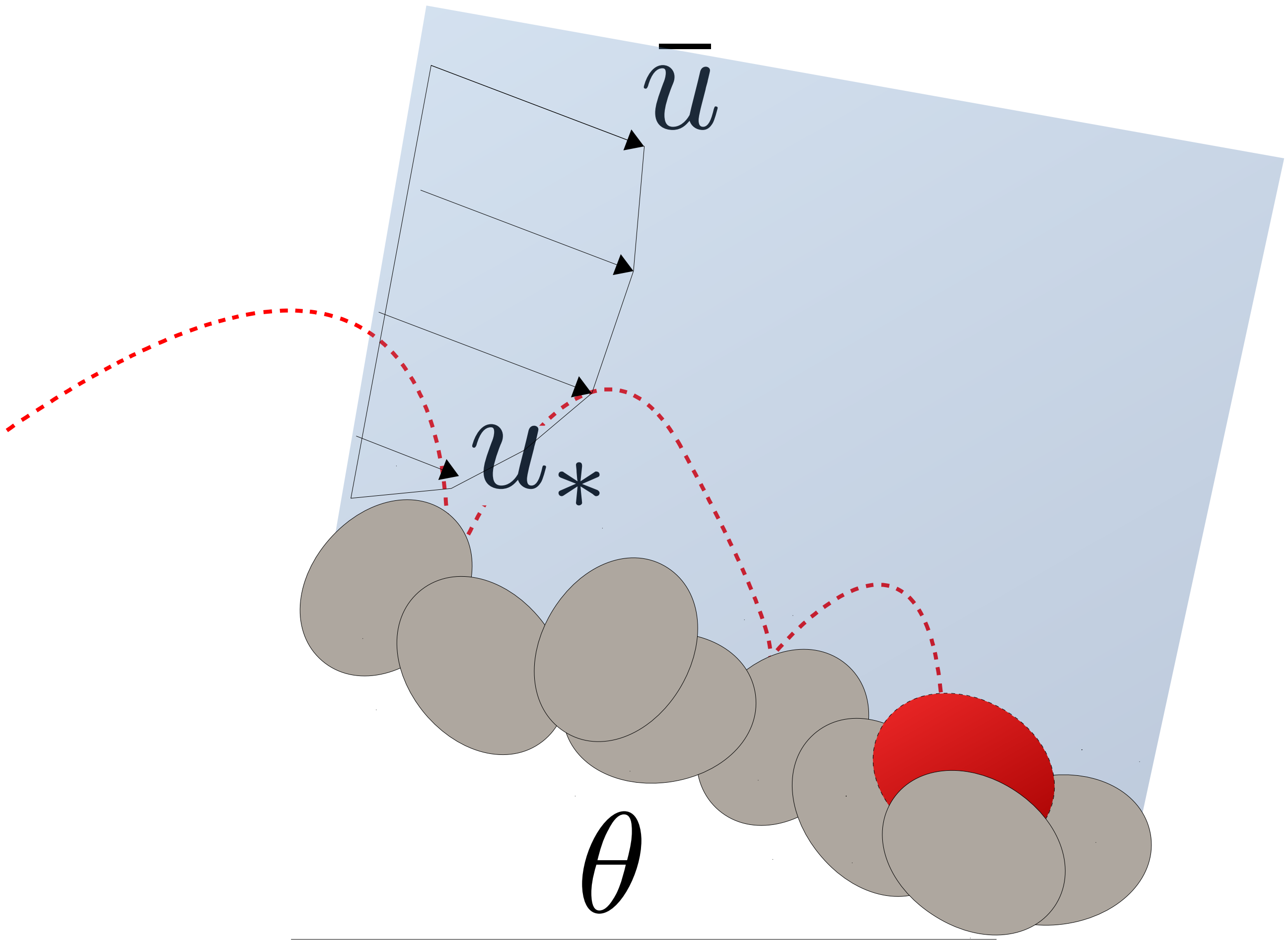


Results

1) Kinematics

2) Deposition

Résultats / Déposition

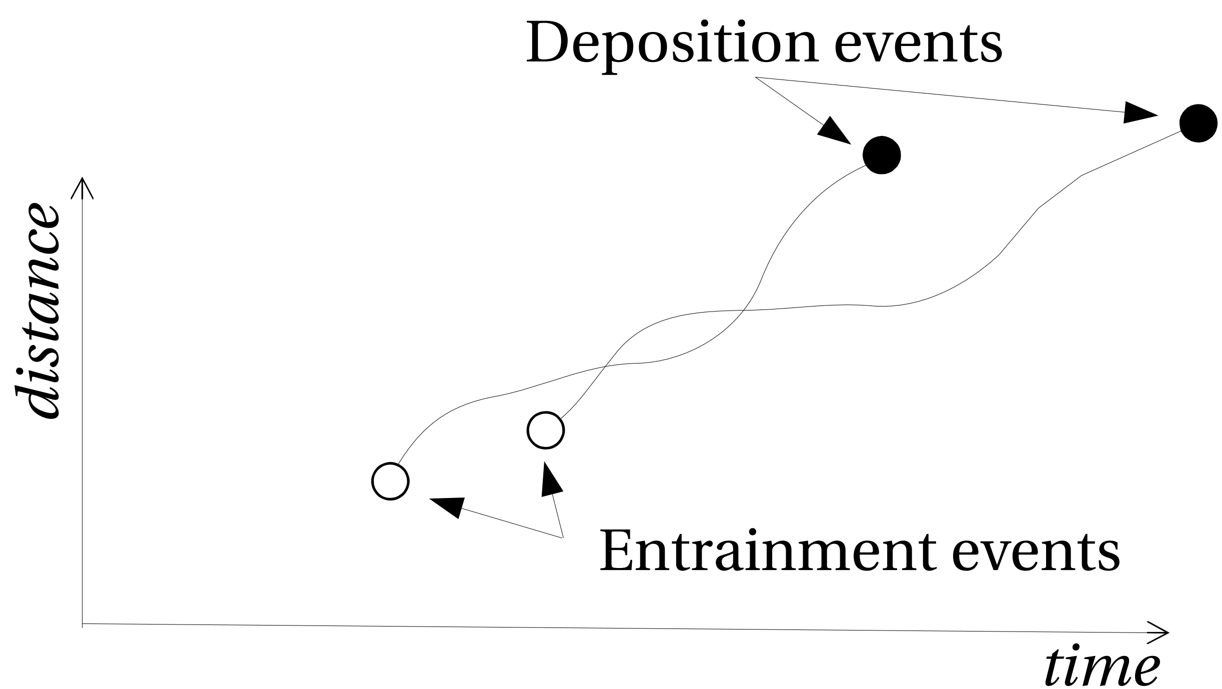


Results / Deposition

Definitions :

Particle deposition rate : $r_{\downarrow p}$ [s^{-1}]

Dimensionless Particle deposition rate : $r^*_{\downarrow p} = r_{\downarrow p} \frac{d_{50}}{w_s}$



Results / Deposition

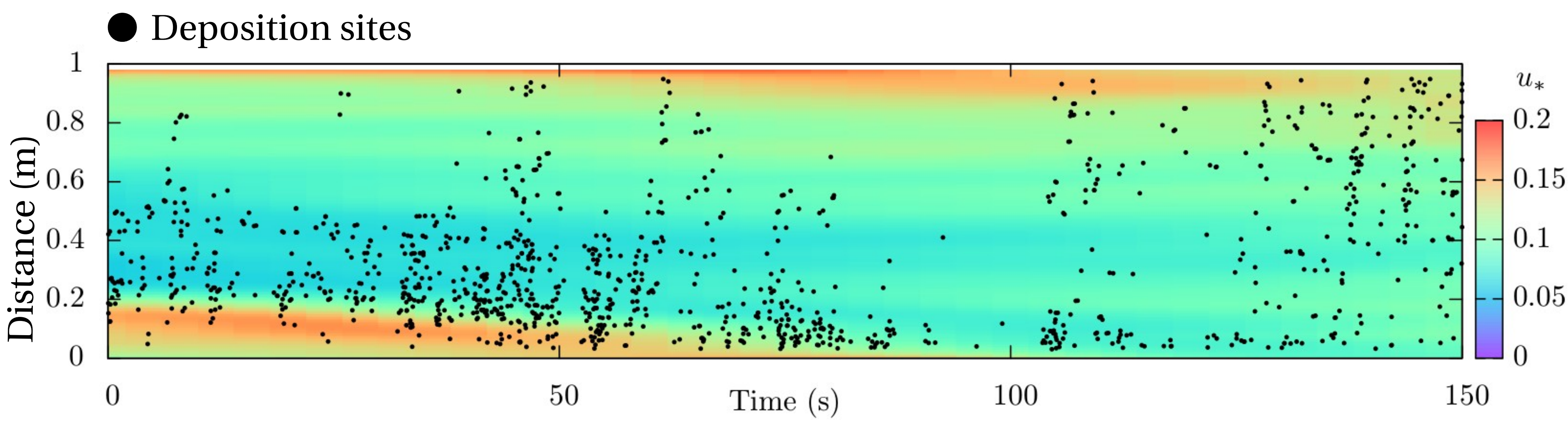
Dependence of deposition rate to shear velocity :

Mean deposition rate

pdf of shear velocities at deposition sites

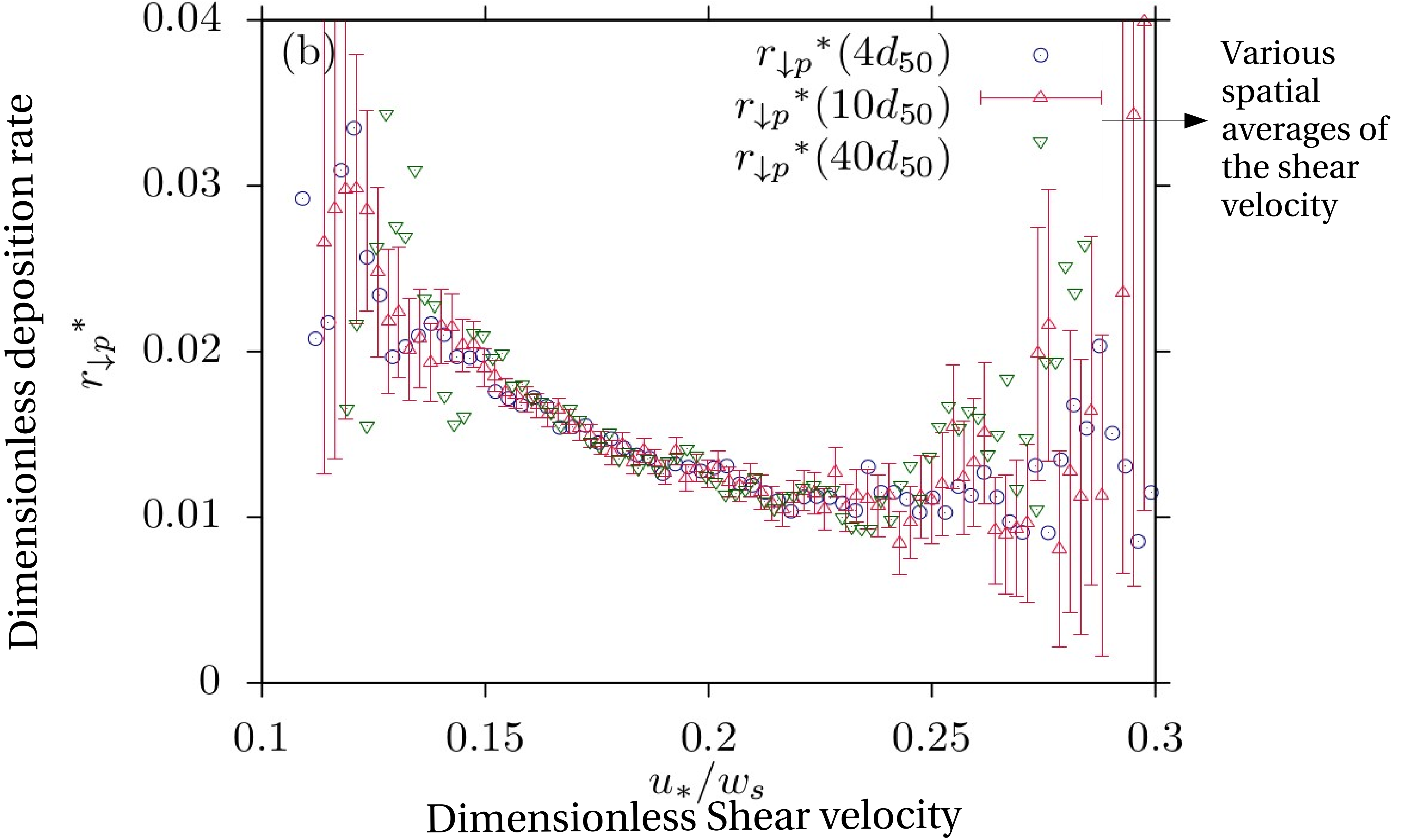
$$r^*_{\downarrow p}(u_*) = \langle r^*_{\downarrow p} \rangle \frac{f_{u_*|D}}{f_{u_*}}$$

pdf of shear velocities anywhere*



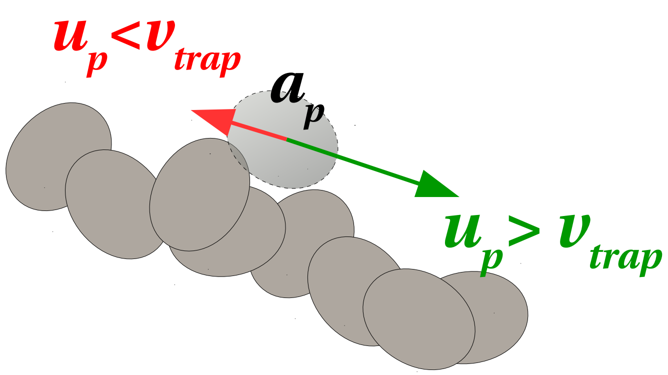
*: on particle trajectories

Résultats / Déposition

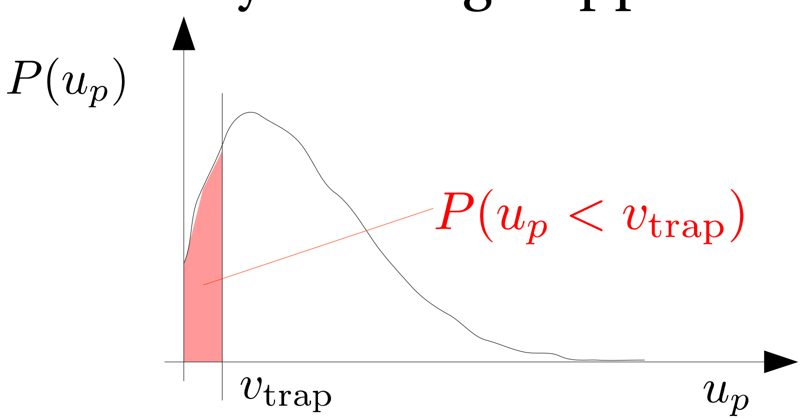


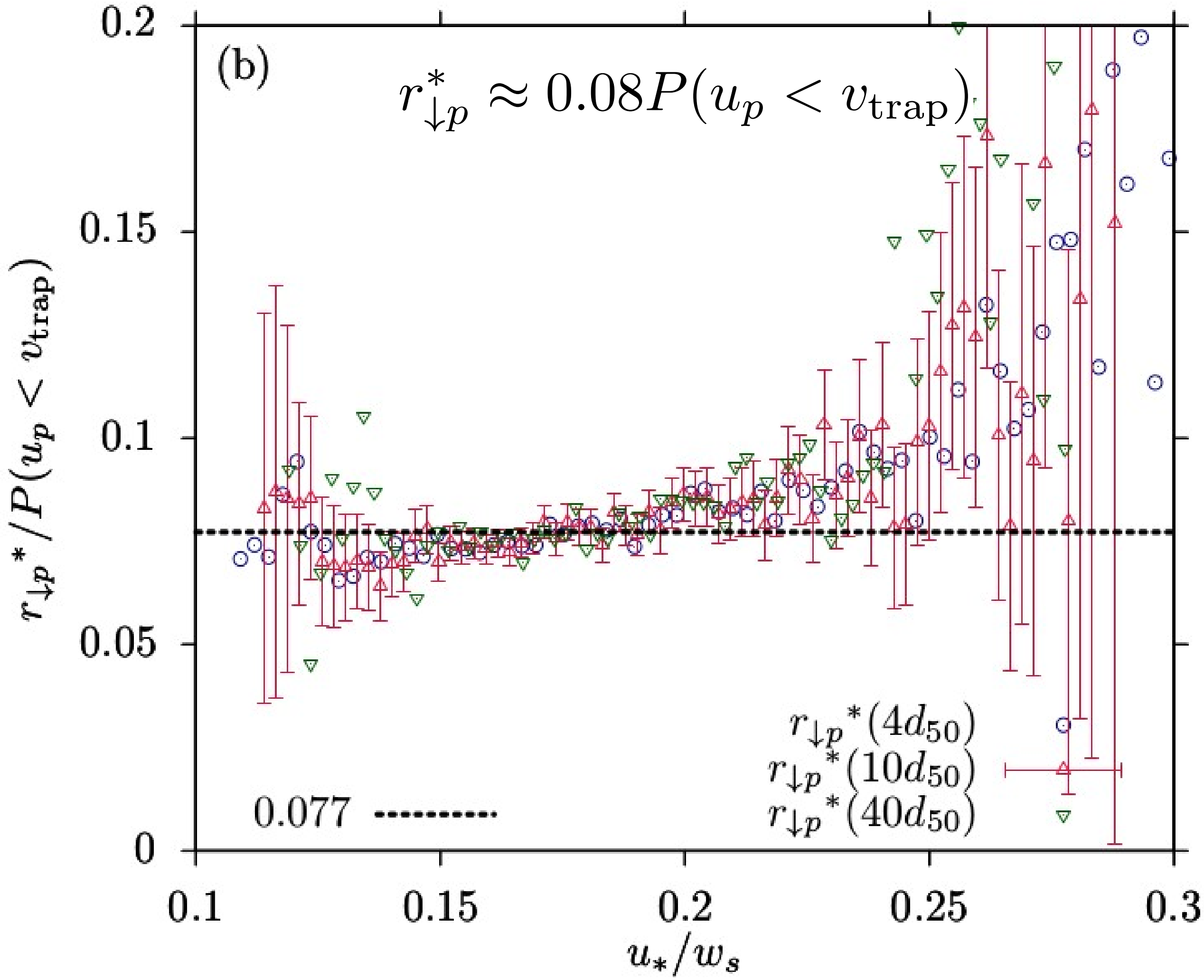
Results / Deposition

Remember Trapping !



Probability of being trapped





DEPOSITION ↔ TRAPPING ?

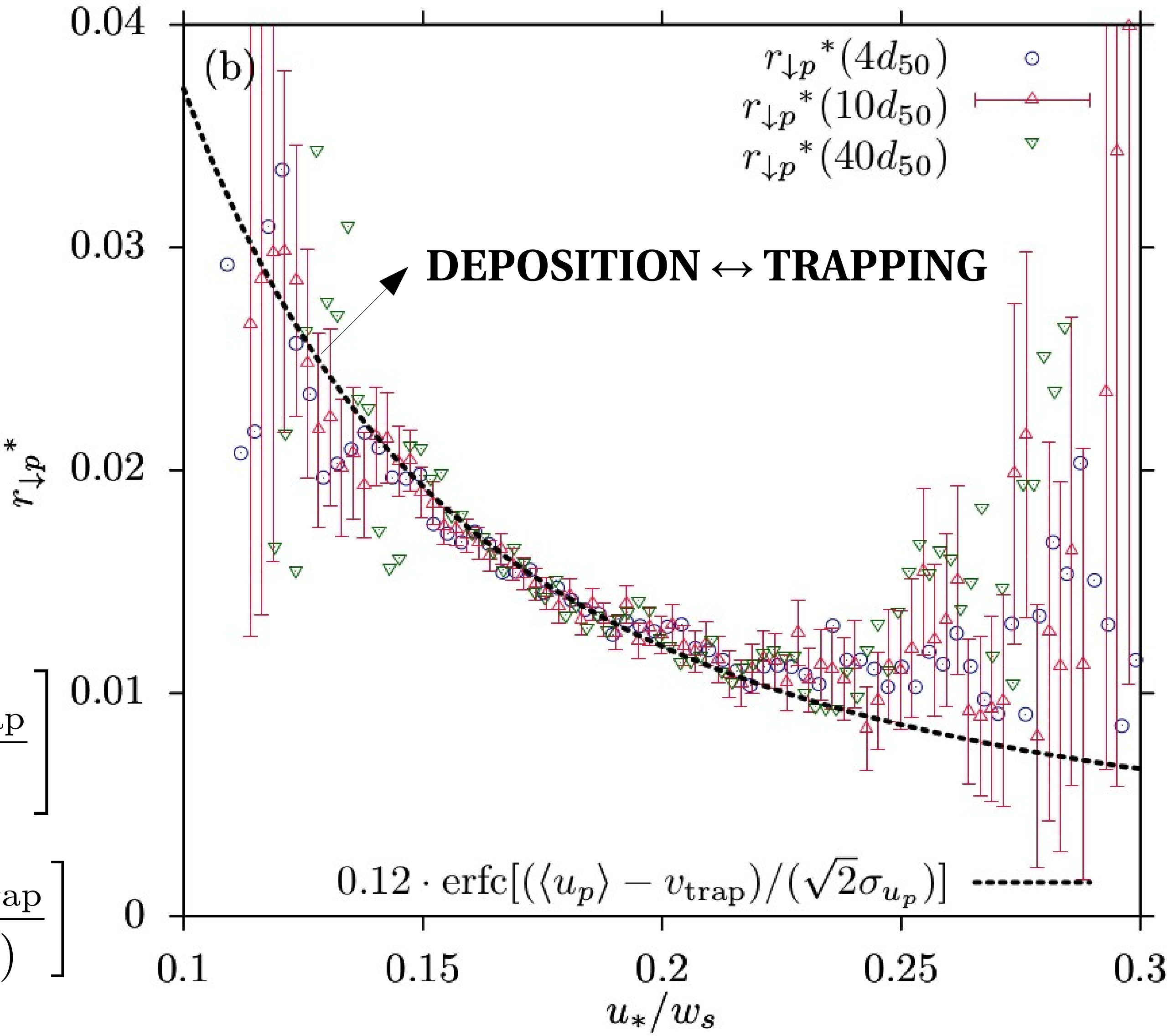
Results / Deposition

Resuming :

$$\langle u_p \rangle \approx 3.65u_* - 0.06w_s$$
$$\sigma_{u_p} \approx 1.38u_* + 0.15w_s$$
$$u_p \sim \text{Gaussian}$$
$$v_{\text{trap}} \approx 0.11 \text{ m/s}$$
$$r^*_{\downarrow p} \propto P(u_p < v_{\text{trap}})$$

$$P(u_p < v_{\text{trap}}) = \text{erfc}\left[\frac{\langle u_p \rangle - v_{\text{trap}}}{\sqrt{2}\sigma_{u_p}}\right]$$

$$r^*_{\downarrow p} \propto \text{erfc}\left[\frac{3.65u_* - 0.06w_s - v_{\text{trap}}}{\sqrt{2}(1.38u_* + 0.15w_s)}\right]$$



Conclusions

A large experimental dataset of particle trajectories
(available online at https://goo.gl/p4GbsR)

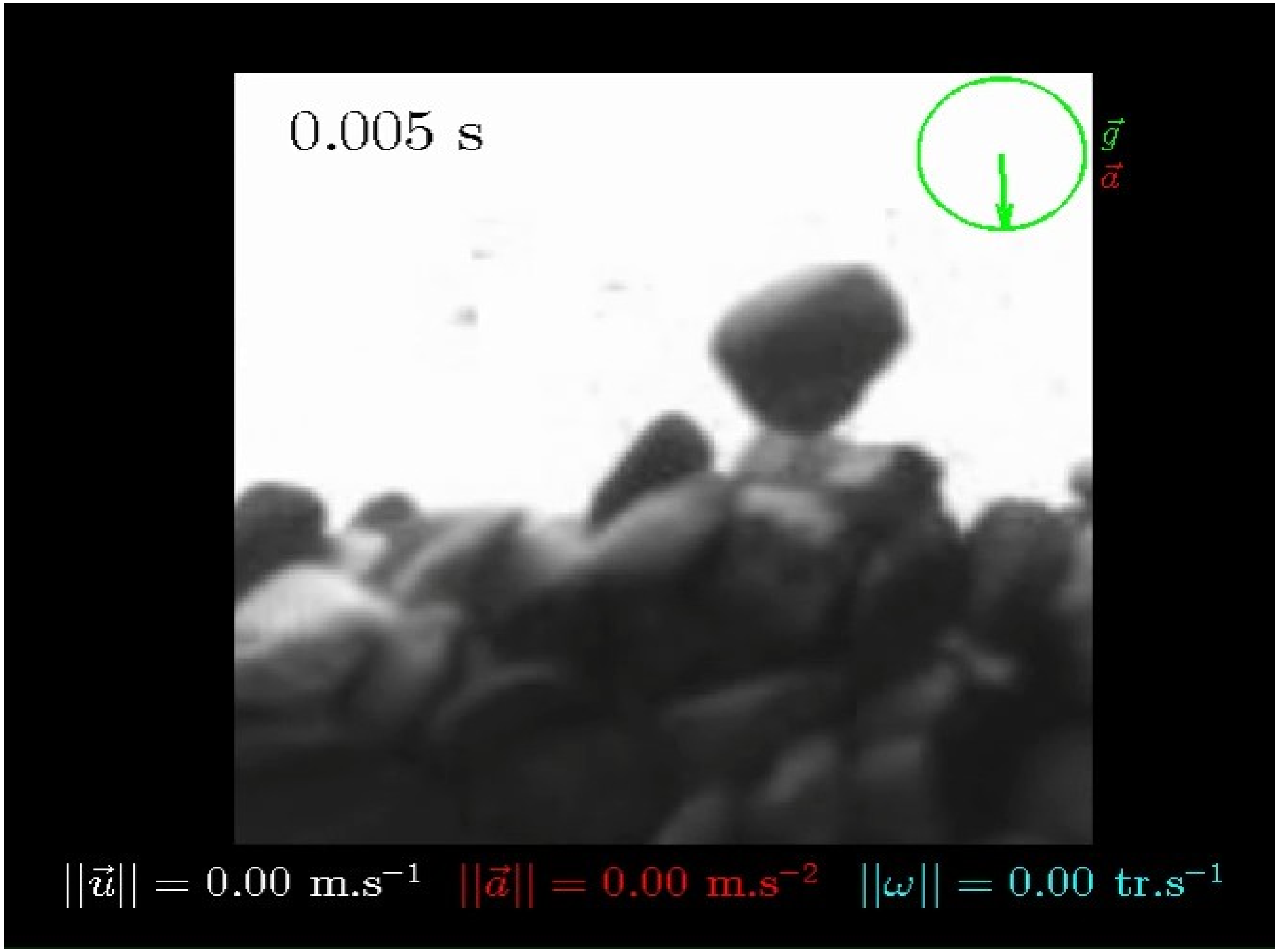
$$\mathrm{Re}_p, \mathrm{St} \approx 10^3, \quad \rho_p/\rho_f = 2.5, \quad \tan\theta \approx 0 - 30\%$$

Close to the onset of motion

- 2 equilibrium particle velocities : 0 and the depth-average flow velocity
- Deposition rates increase dramatically while decreasing flow strength
- Trapping mainly govern particle deposition

Outlook

→ **Particle entrainment is triggered by particles in motion**



→ **~ Splash ?!**