Particle motion over a smooth bed: effect of shape

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Session GM10.3
Assessing geomorphological, hydrological and ecological processes in rivers to inform restoration of riverscape resilience

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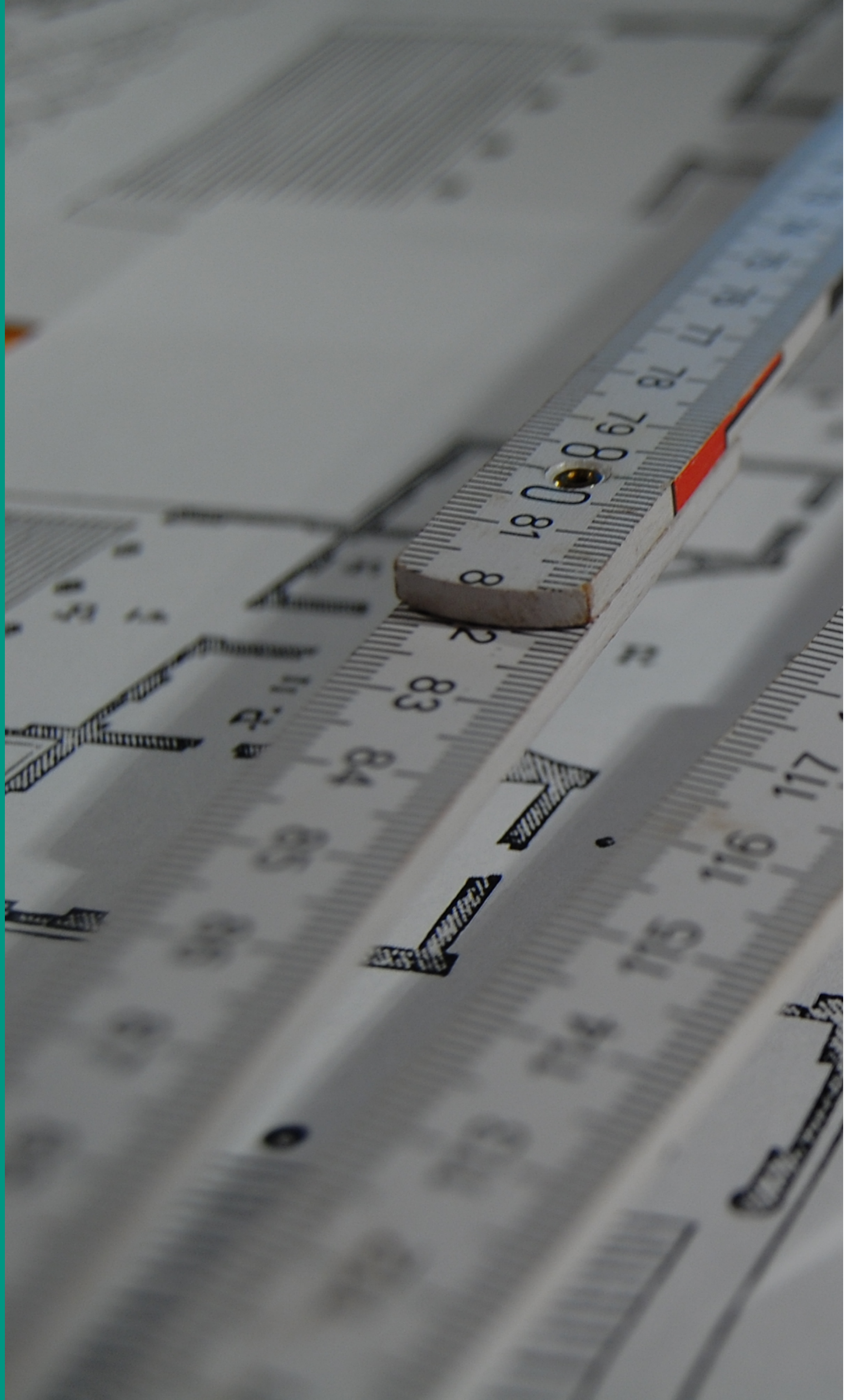


Institute for Water and Environment

Introduction

Context

- There is a growing interest in studying the effect of shape on transport processes in rivers.
- Recent studies have focused on the impact of shape on bedload transport Cassel u. a. 2021; Deal u. a. 2023.
- Additionally, shape is an important factor in characterizing the properties of macroplastics in rivers Russell, Pohl und Fernández 2025.

Concept

Let’s focus entirely on particle shape using precisely controlled 3D-printed geometries. Naturally, there is a trade-off: this approach limits the study to flow over a smooth bed rather than an erodible one.

Research question

What is the effect of particle shape on bedload transport over a smooth bed?

Dimensional Analysis

Functional relationship

$$f(\eta, \rho, \nu, g, H, u_*, \rho_s - \rho, d_1, d_2, d_3, V) \quad (1)$$

Π- Theorem

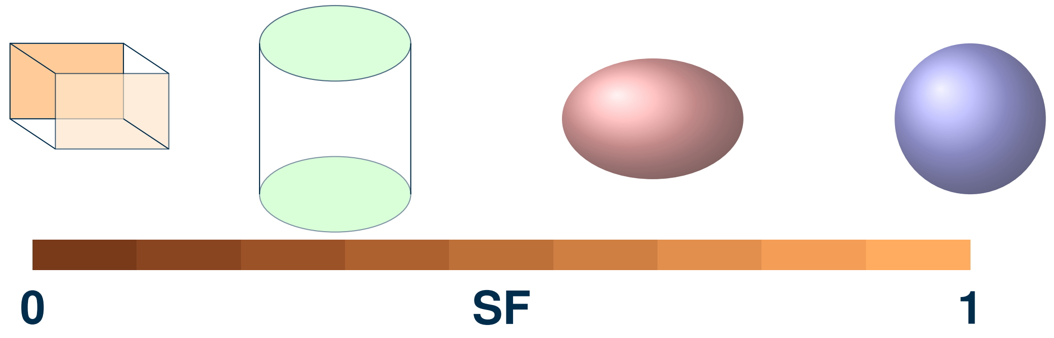
$$f\left(\eta_0, Re_p = \frac{\nu}{\sqrt{g\Delta d_n^3}}, \theta = \frac{\rho u_*^2}{(\rho_s - \rho) g d_n}, \frac{H}{d_n}, \Delta = \frac{(\rho_s - \rho)}{\rho}, \frac{d_2}{d_n}, \frac{d_1}{d_3}, SF = \frac{d_3}{\sqrt{d_1 d_2}}\right) \quad (2)$$

Effect of shape only

$$f\left(\eta_0, SF = \frac{d_3}{\sqrt{d_1 d_2}}\right) = 0 \quad (3)$$

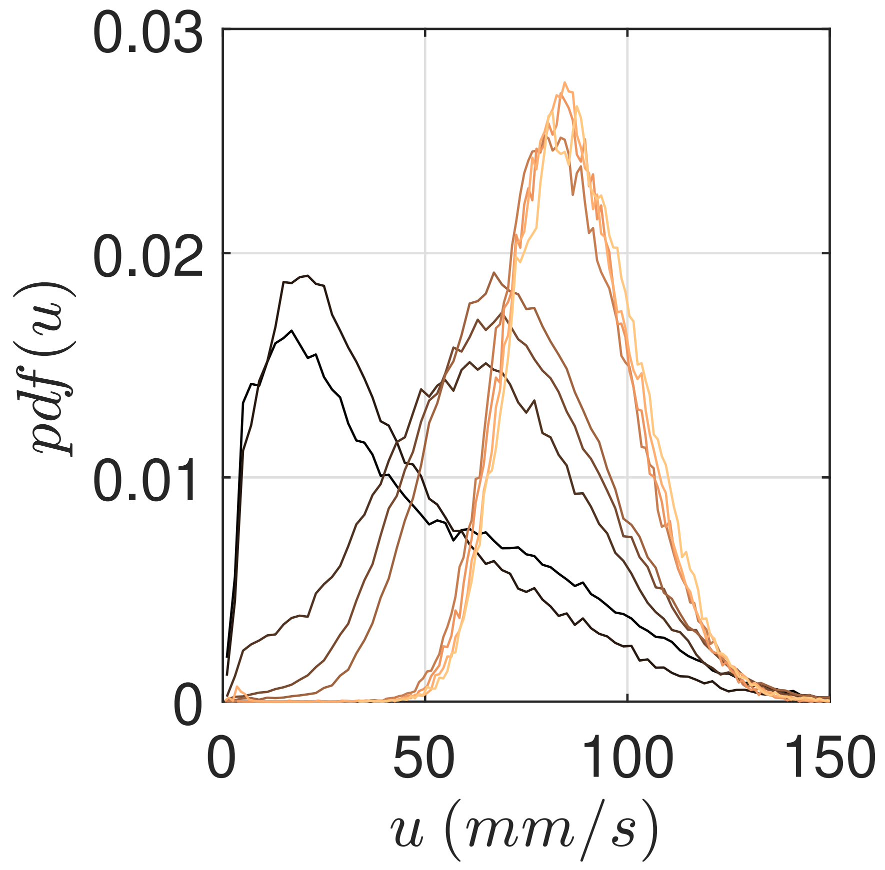
- η: Any state variable (e.g., average particle velocity)
- ρ: Fluid density
- ν: Fluid viscosity
- g: Acceleration due to gravity
- H: Channel depth
- u_*: Friction velocity, $u_* = \sqrt{\tau/\rho}$
- ρ_s: Particle density
- d_1, d_2, d_3: Particle dimensions, $d_1 > d_2 > d_3$
- V: Volume of the particles

Experiments

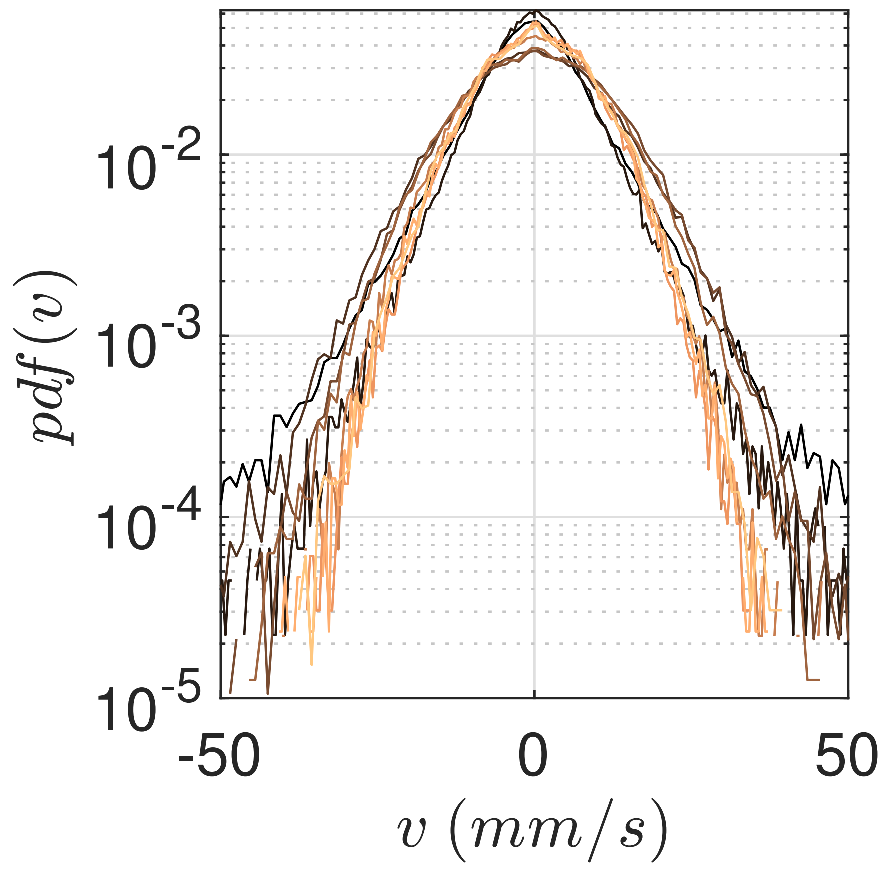


- Rectangular channel flow (5.80 m length, 0.40 m width, 0.15 m height).
- $Q = 13\,\text{l/s}$ and $U = 0.22\,\text{m/s}$
- 2 GoPro Hero Black 7 cameras (capturing $1 \times 0.3\,\text{m}^2$ areas)
- 30 frames per second with a resolution of 1.86 pixels/mm.
- Particle positions were identified using Streams PTV software, with intensity thresholds and cost function-based tracking algorithms.
- Reconnection of particle paths was performed where tracking was lost, with a maximum offset of 2 frames and search windows of $\pm 10\,\text{mm}$.

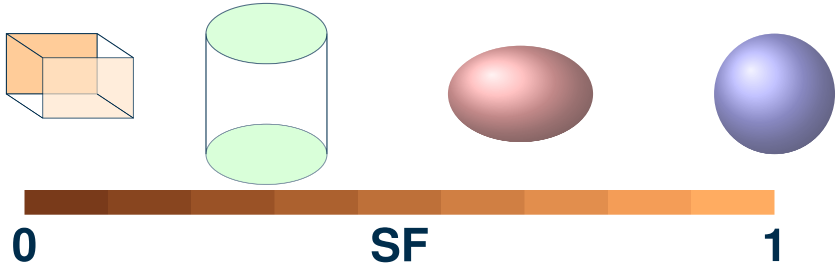
Velocity



0.03
0.02
0.01
0
0
50
100
150
$pdf(u)$
$u\ (mm/s)$

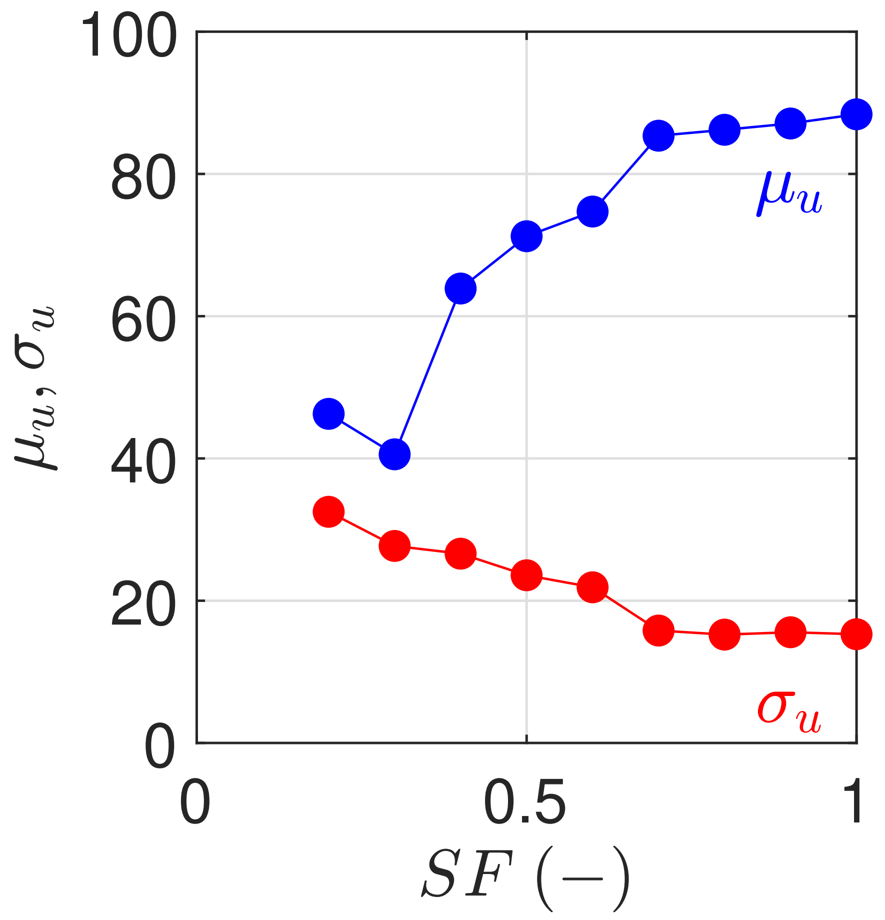


10^{-2}
10^{-3}
10^{-4}
10^{-5}
-50
0
50
$pdf(v)$
$v\ (mm/s)$

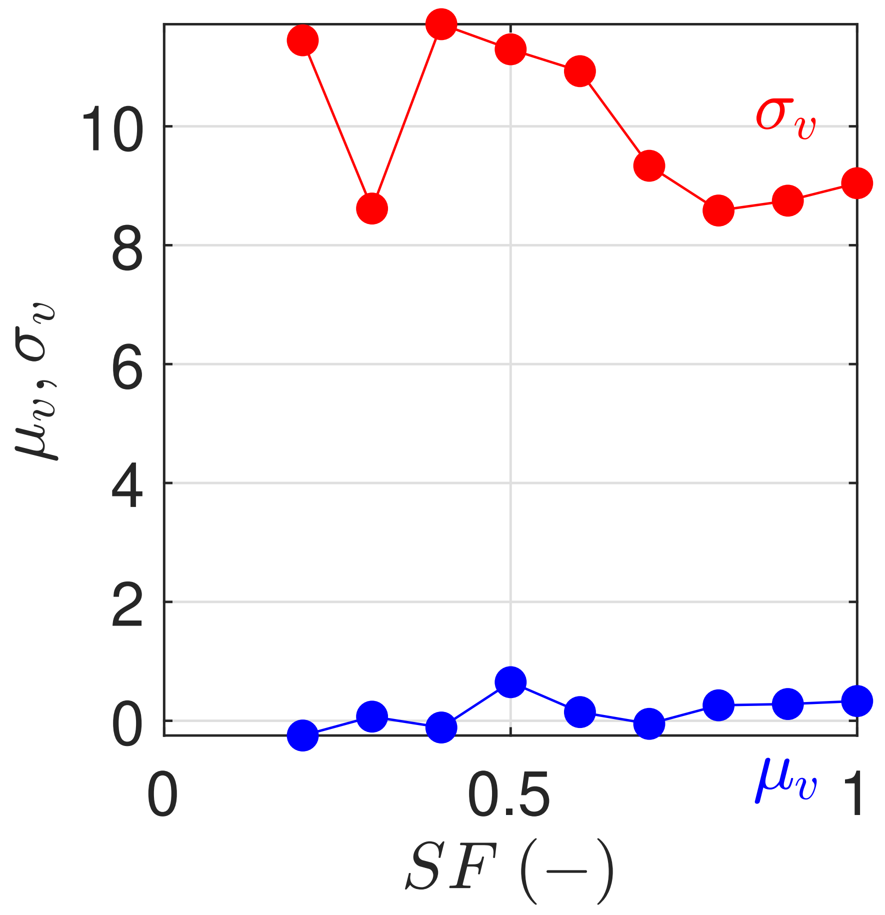


0
SF
1

Velocity

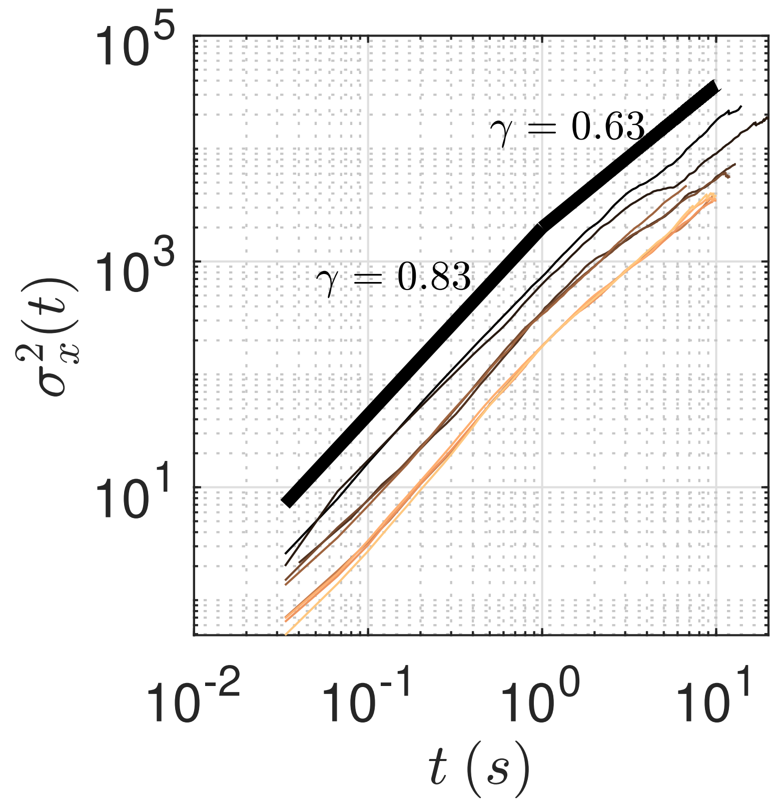


100
80
60
40
20
0
0
0.5
1
μ_u, σ_u
μ_u
σ_u
$SF\ (-)$

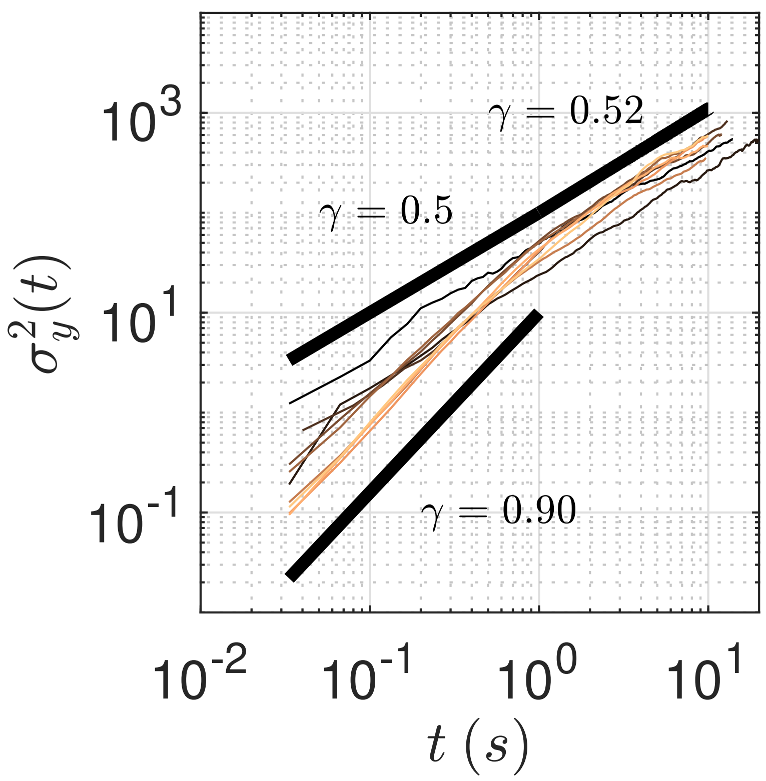


10
8
6
4
2
0
0
0.5
1
μ_v, σ_v
σ_v
μ_v
$SF\ (-)$

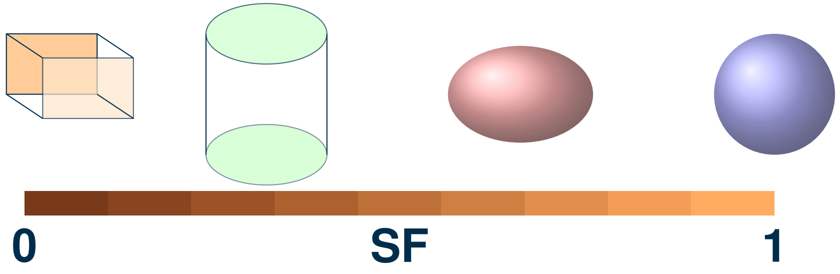
Diffusion



$\gamma = 0.63$
$\gamma = 0.83$
10^5
10^3
10^1
$\sigma_x^2(t)$
10^{-2} 10^{-1} 10^0 10^1
$t\ (s)$



$\gamma = 0.52$
$\gamma = 0.5$
$\gamma = 0.90$
10^3
10^1
10^{-1}
$\sigma_y^2(t)$
10^{-2} 10^{-1} 10^0 10^1
$t\ (s)$



0
SF
1

Conclusions

Preliminary conclusion

- Average of u increases for increasing SF
- Variance of u and v decrease for increasing SF
- Streamwise direction: super-diffusive
- Transversal direction: normal diffusion for large time and prism.

InMoBed

- New project @KIT
- Mario Franca, Daniel Valero and Frank Seidel
- Plastic in rivers as bedload
- Incipient motion and transport

Website

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