Modelling of dune patterns by short range interactions

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Objectives

Implement a model conceptual enough to be applied on different types of geomorphological environments from aeolian dunes to river beds.

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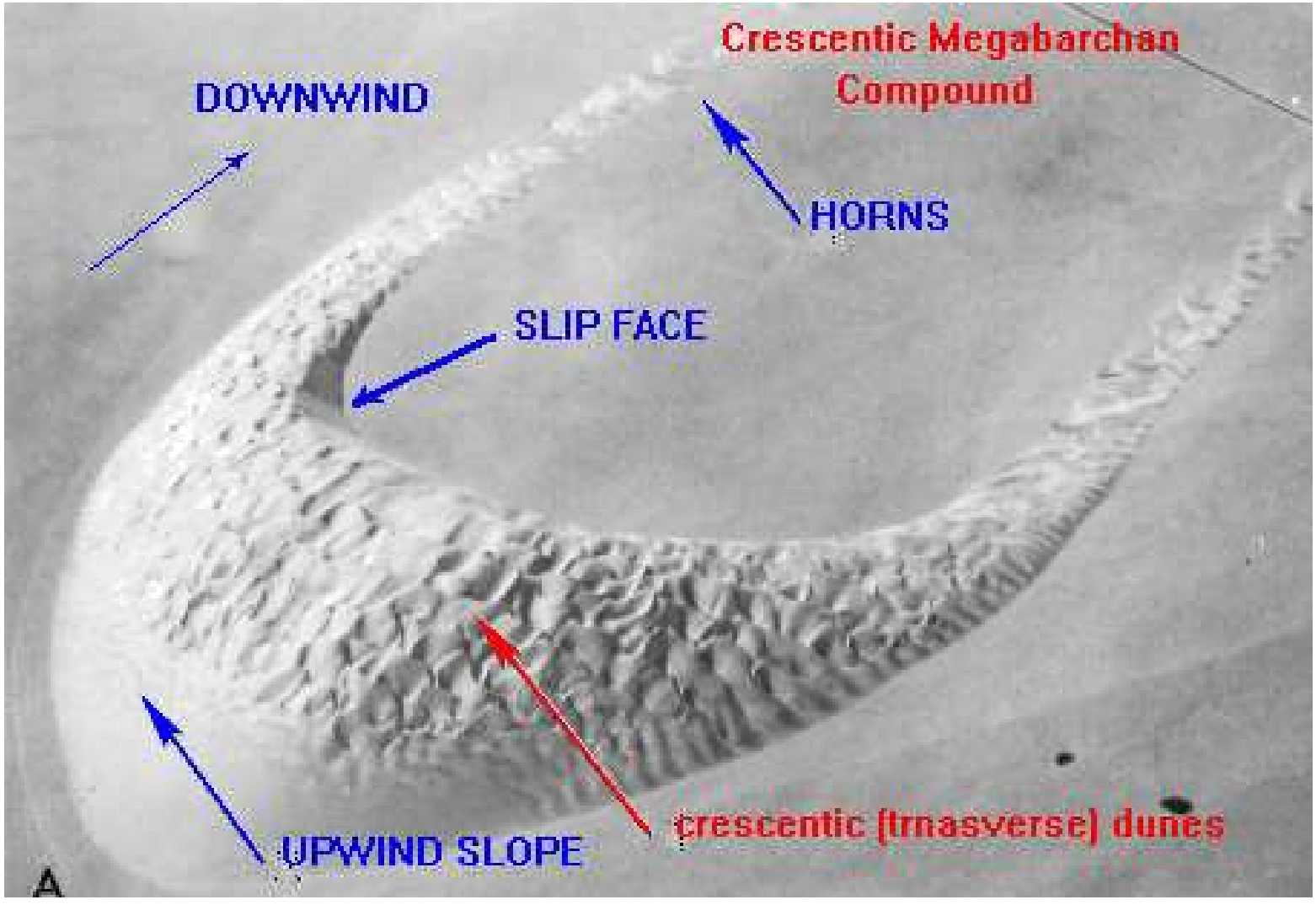
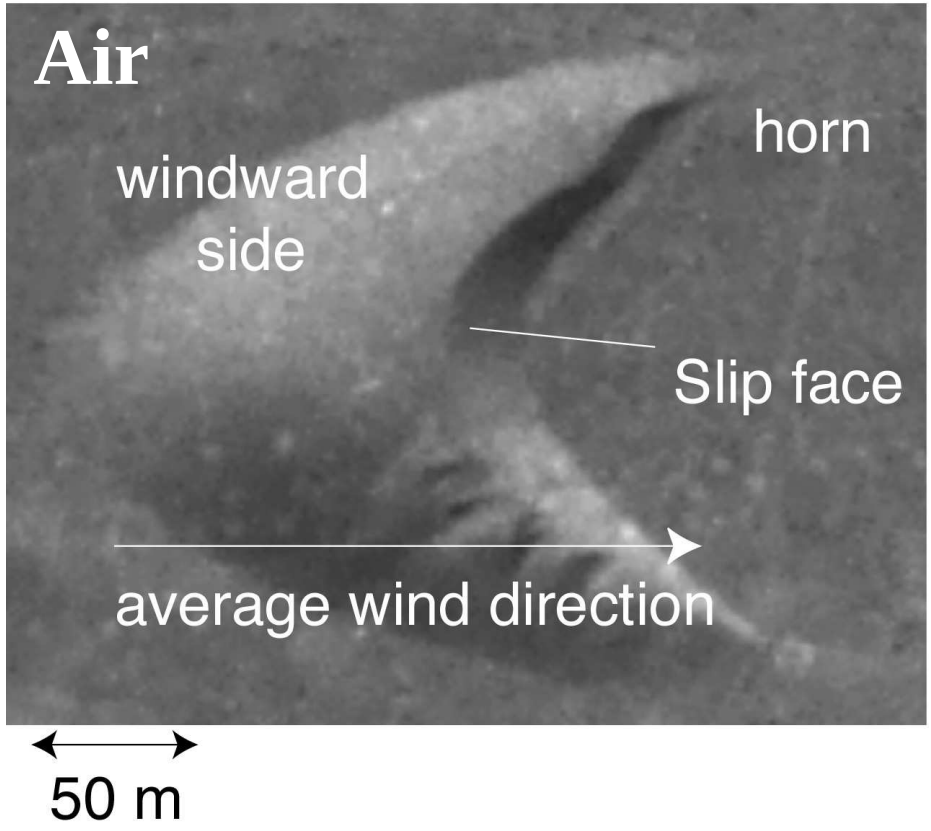
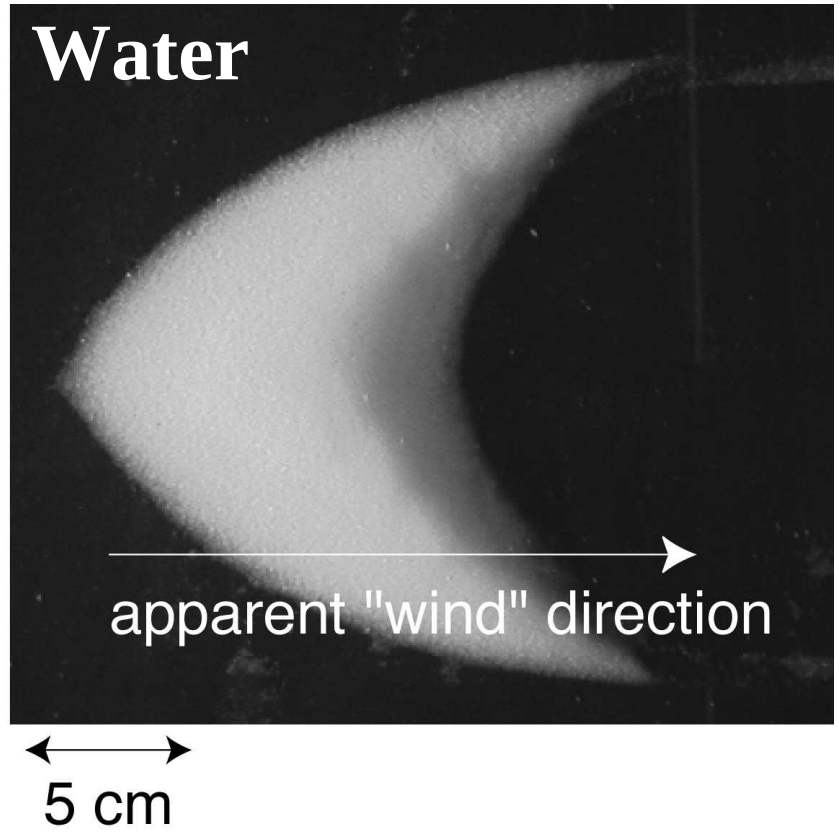
Validate our aproach by data and independent theoritical framework and numerical approach.

Barchan dunes




Air
horn
windward
side
Slip face
average wind direction
50 m


Water
apparent "wind" direction
5 cm


windward
face
slip face
horn
horn
wind direction


1 km
Image © 2005 DigitalGlobe
© 2005 Google
Pointer 17°32'22.92" N 16°39'33.56" E
Streaming 100%
Eye alt 16.47 km

The physics of aeolian dunes

h the height profile

q the volumic sand flux

$$\frac{\partial h}{\partial t} = -\frac{\partial q}{\partial x}$$

q_s the saturated sand flux

$$\frac{\partial q}{\partial x} = \frac{q_s - q}{L}$$

An elegant formalism which gives solutions that can be used as a benchmark for numerical codes.

What is a cellular automaton?

A cellular automaton is a collection of cells interacting via simple rules.

Each cell can be assigned a scalar/state property.

This property changes due to

$\longrightarrow$ external forcing affecting all cells.

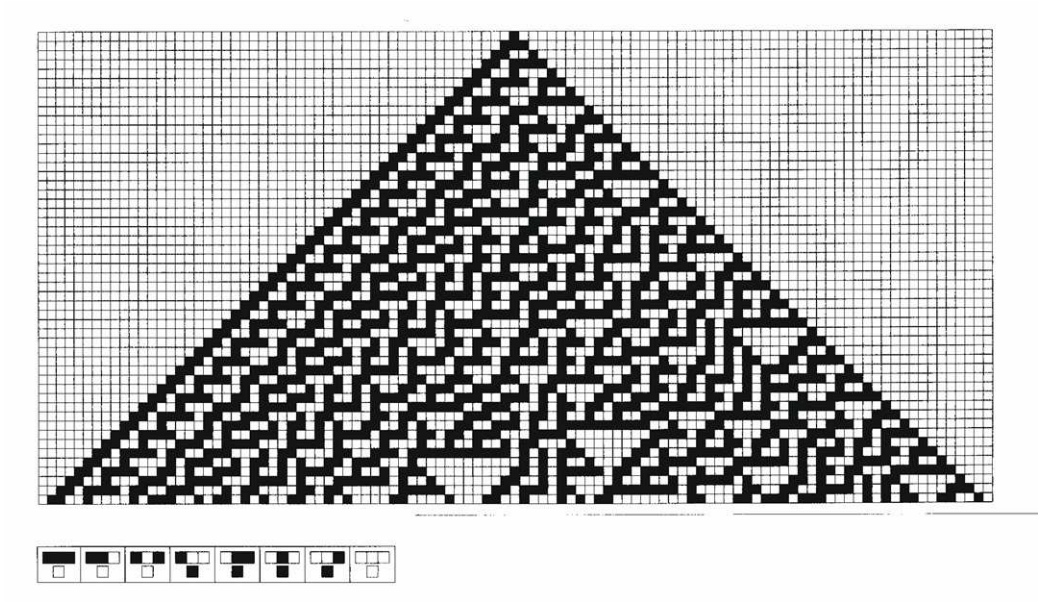
$\longrightarrow$ *internal interactions* between cells.

The external forcing is often assumed to occur at a constant rate, and the *internal interactions* are usually simplified to include only nearest neighbour interactions.

Paradigm for complex systems

Emergence of structures from the interactions between the constituent parts of a system.

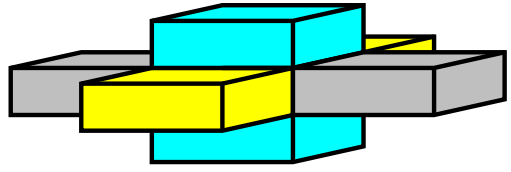
Applications

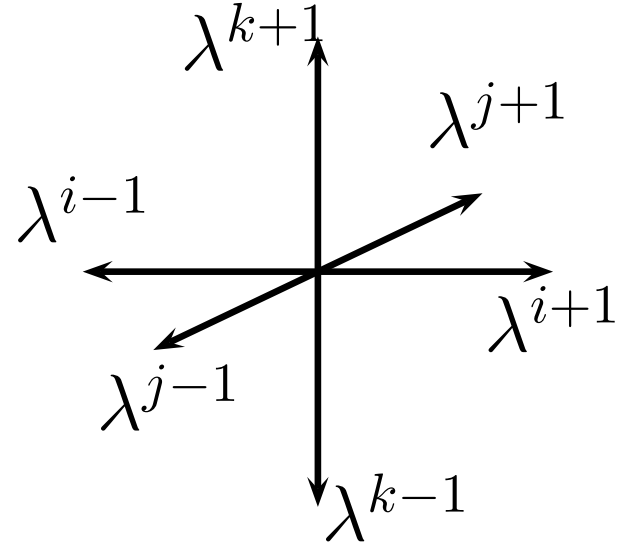


Murray, A.B. and Paola, C. (1994). *A cellular automaton for braided rivers*, Nature, 371, 54.

Nishimori, H. and Ouchi, N. (1993). *Computational models for sand ripple and sand dune formation*, Int. J. of Mod. Phys. B, 7, 2025.

A discrete model



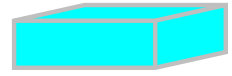


a 3 dimensional cellular automaton

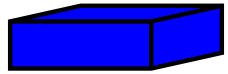
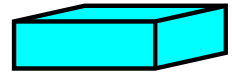
An elementary cell  has a slab shape with a square base of length l_d and a height h:

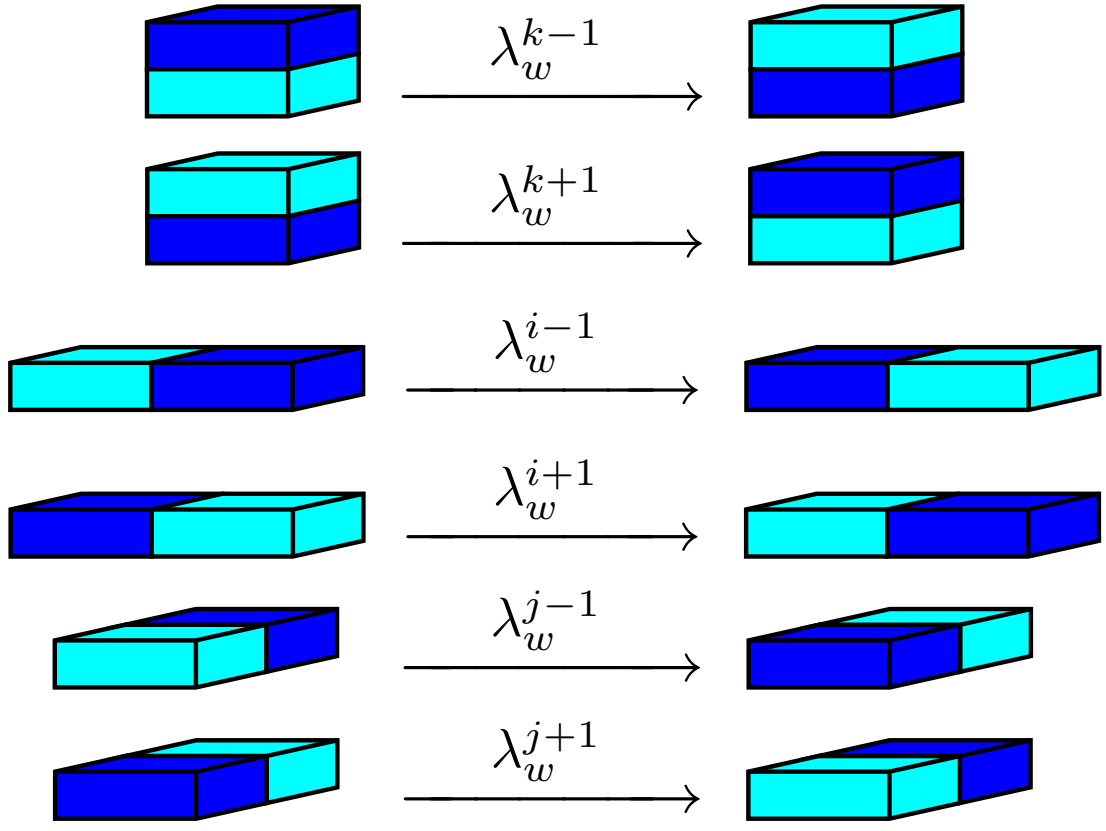
$$l_d = \frac{\rho_s}{\rho_f} d, \qquad \eta = \frac{h}{l_d} \qquad \Rightarrow \qquad \tau = \frac{l_d h}{Q}$$

4 different states, 2 solid, 2 fluid

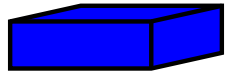
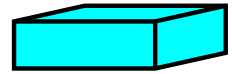
Action of fluid shear stress on topography	 grains (G)
	 mobilized grains (M)
Action of topography on fluid motions	 fluid (F)
	 excess shear stress (S)

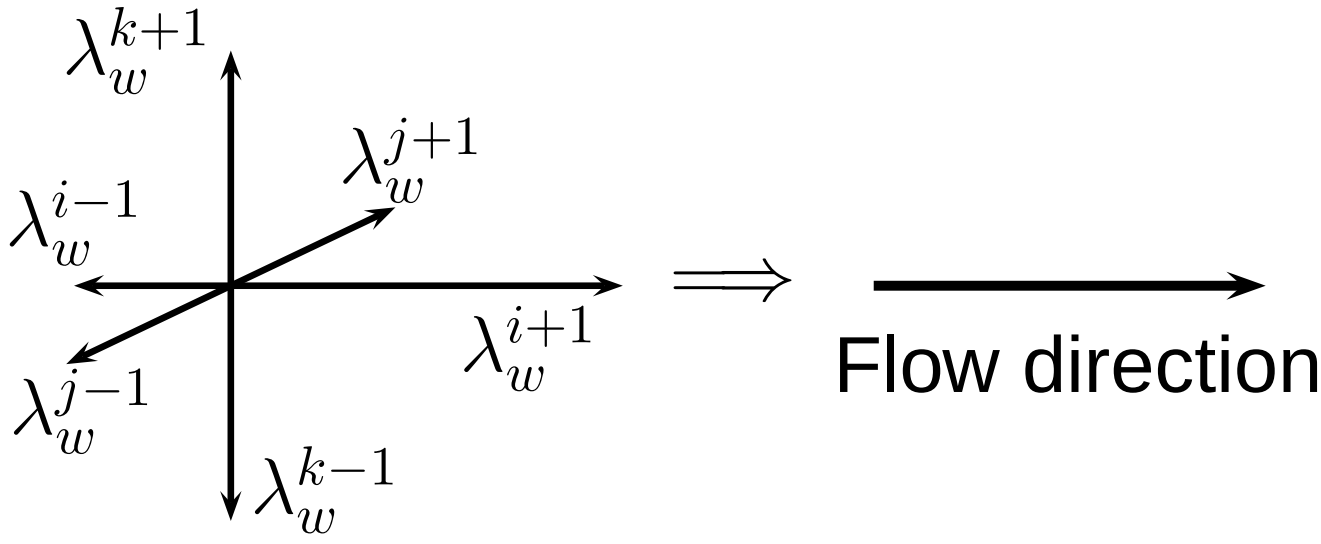
The fluid flow

Motions of  cells with respect to  cells.



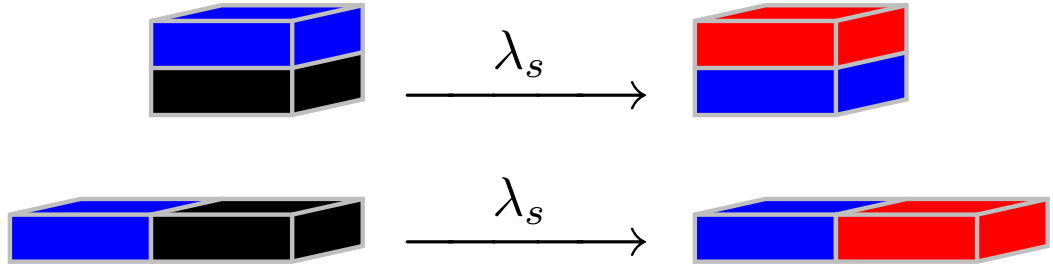
The fluid flow

Motions of  cells with respect to  cells.



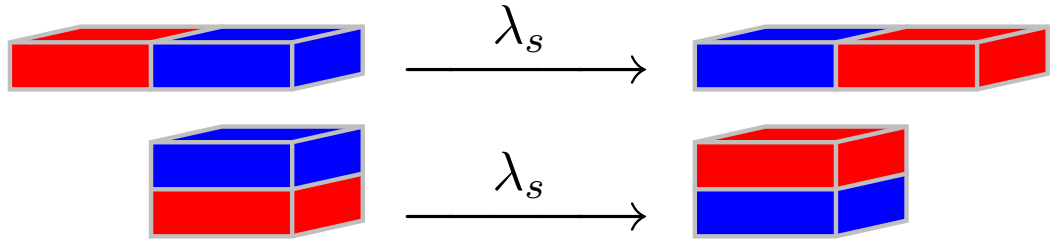
Erosion

Contacts between  cells and  cells produce  cells.



Transport

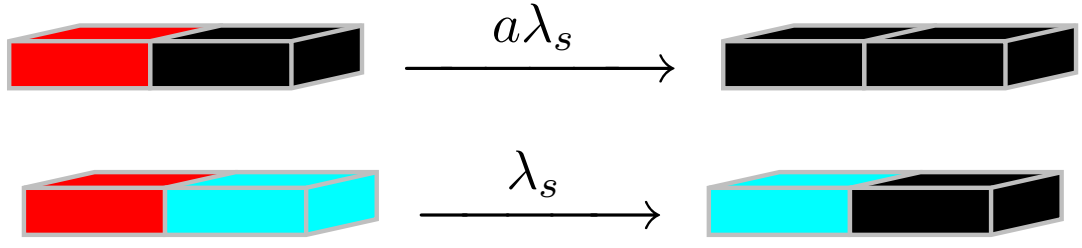
Motions of  cells with respect to  cells.

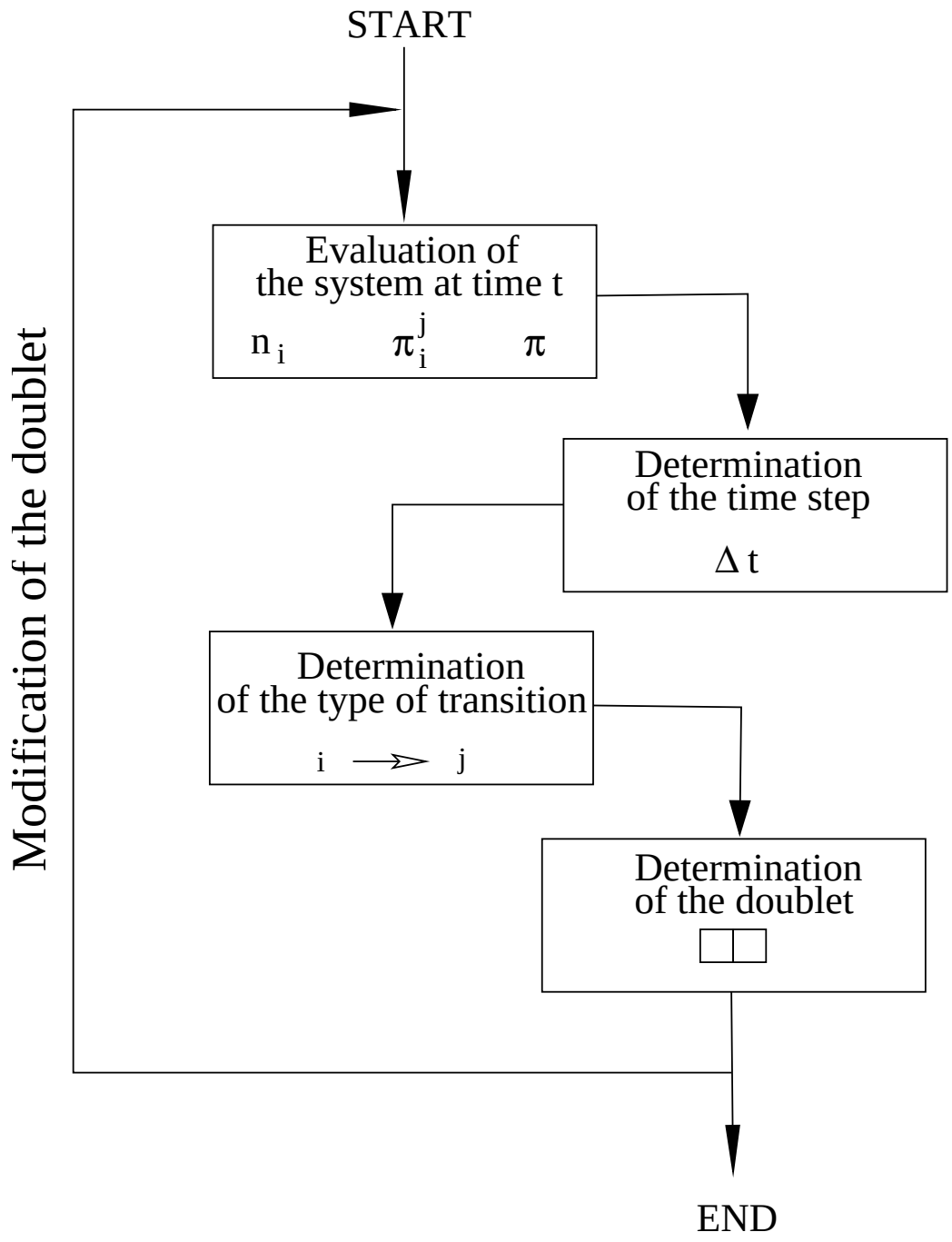


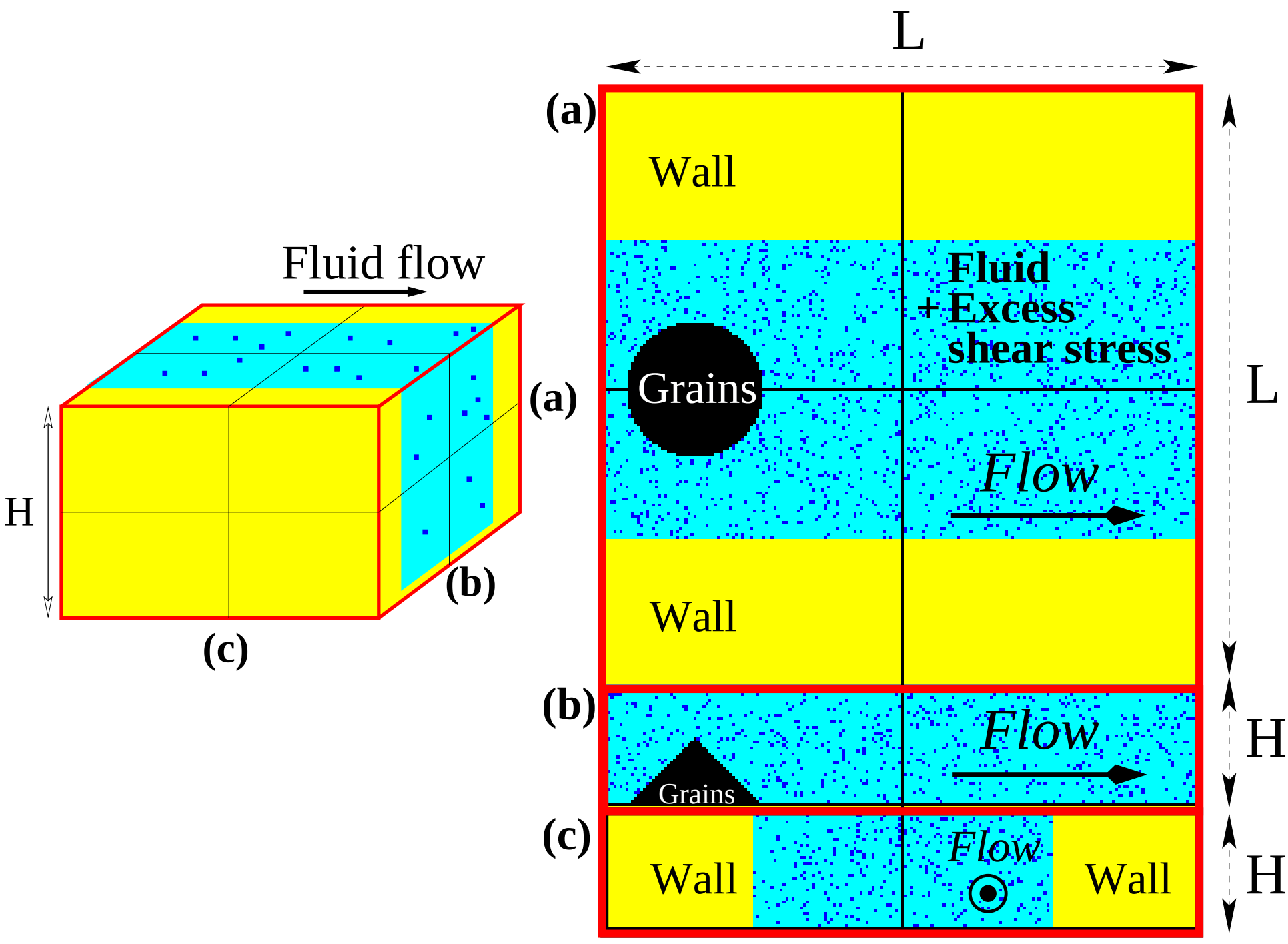
Deposition

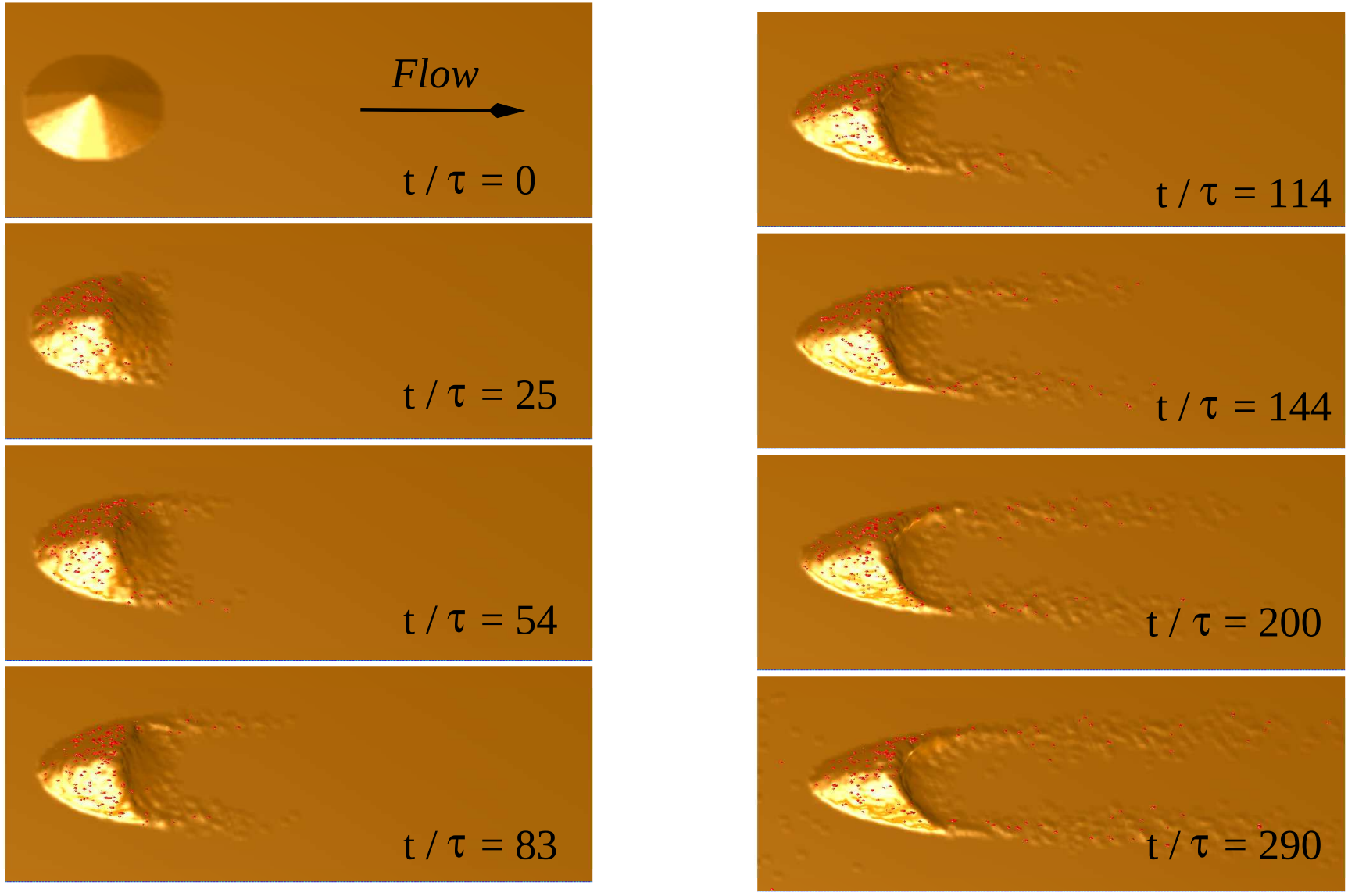
Contacts between  and  or 

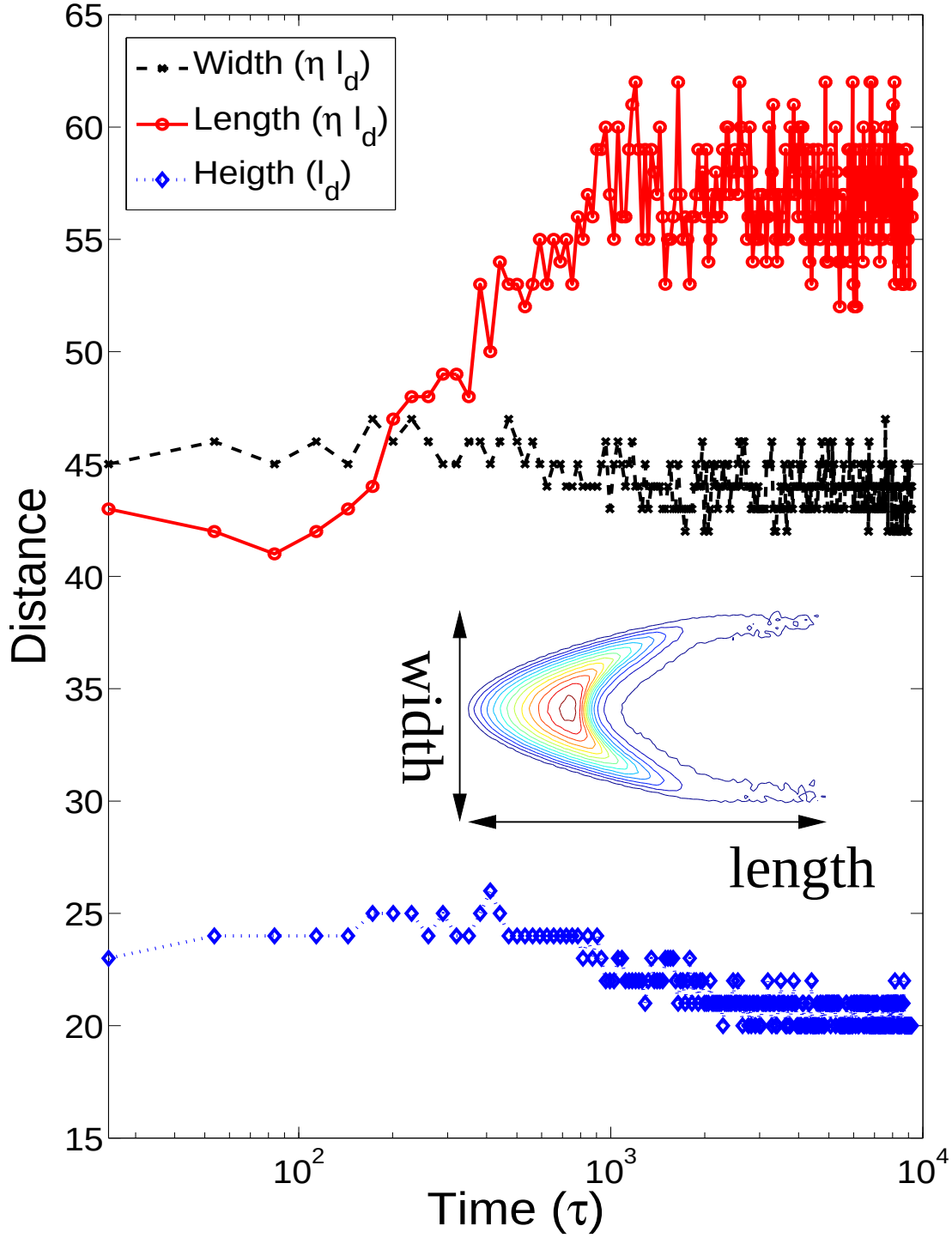
cells produce  cells.

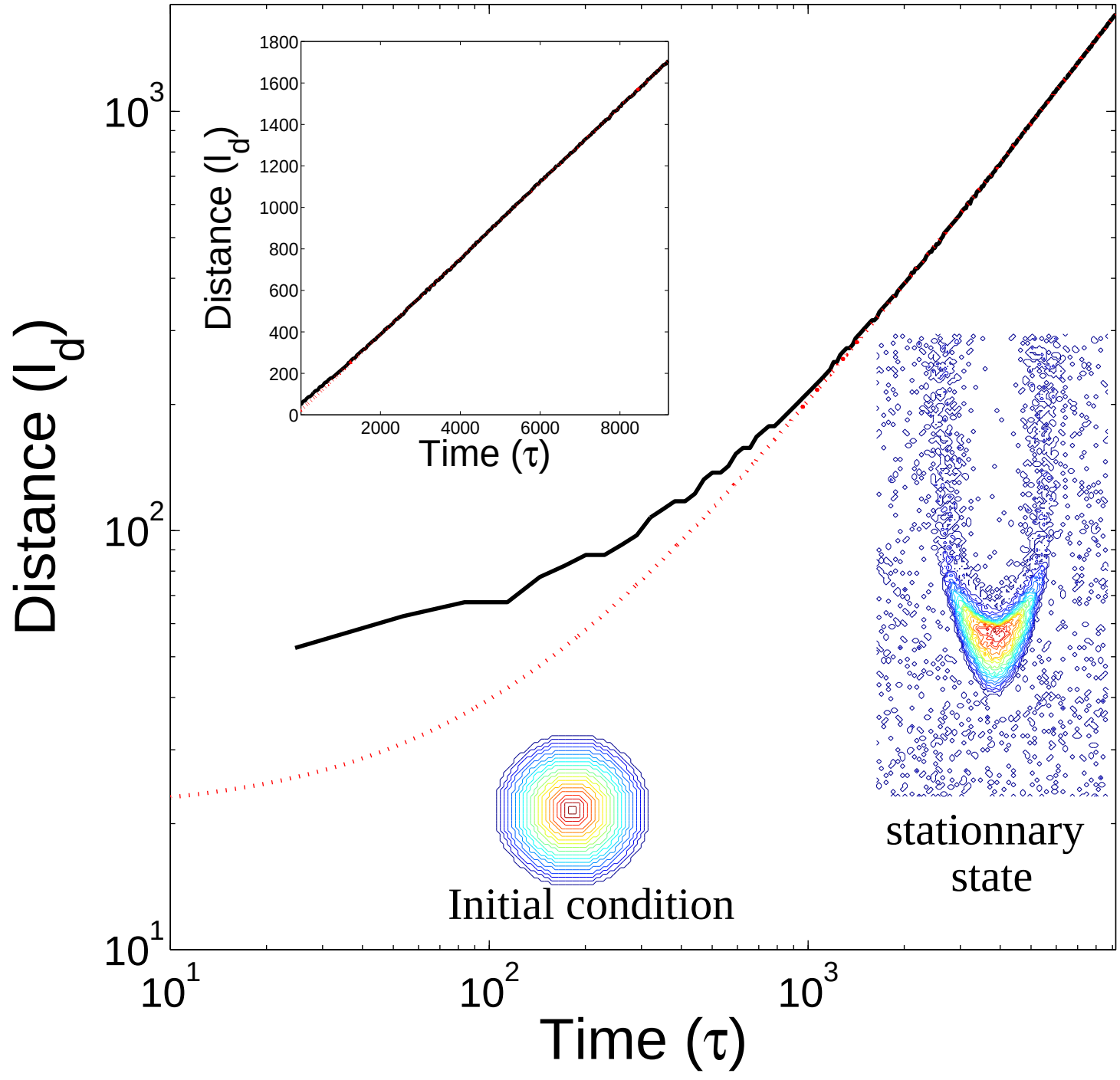


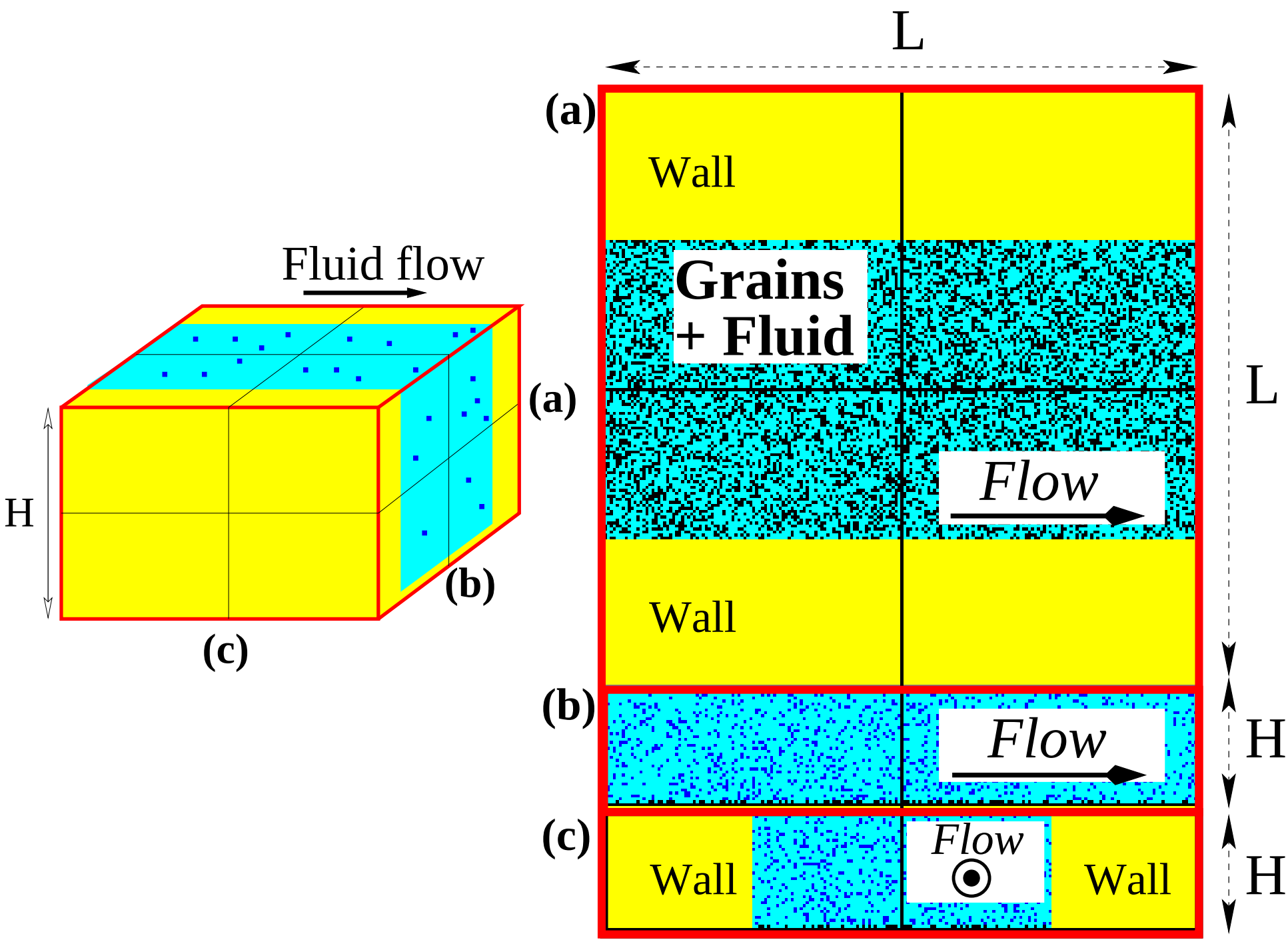

START
Evaluation of
the system at time t
n_i π_i^j π
Determination
of the time step
Δt
Determination
of the type of transition
i → j
Determination
of the doublet
Modification of the doublet
END

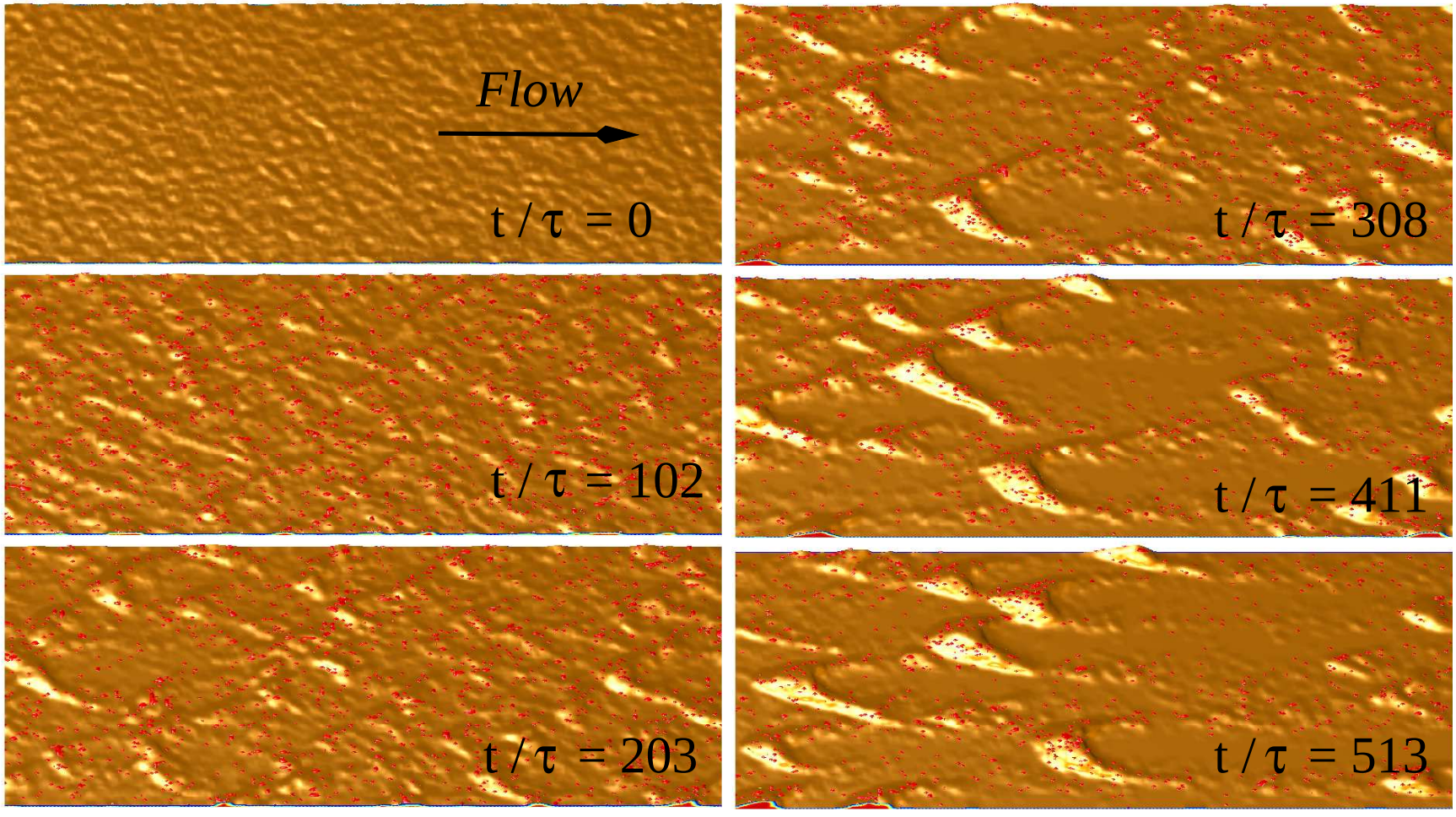

L
(a)
Wall
Fluid
+ Excess
shear stress
Grains
Flow
L
Wall
(b)
Flow
H
Grains
(c)
Flow
Wall
Wall
H
Fluid flow
(a)
H
(b)
(c)

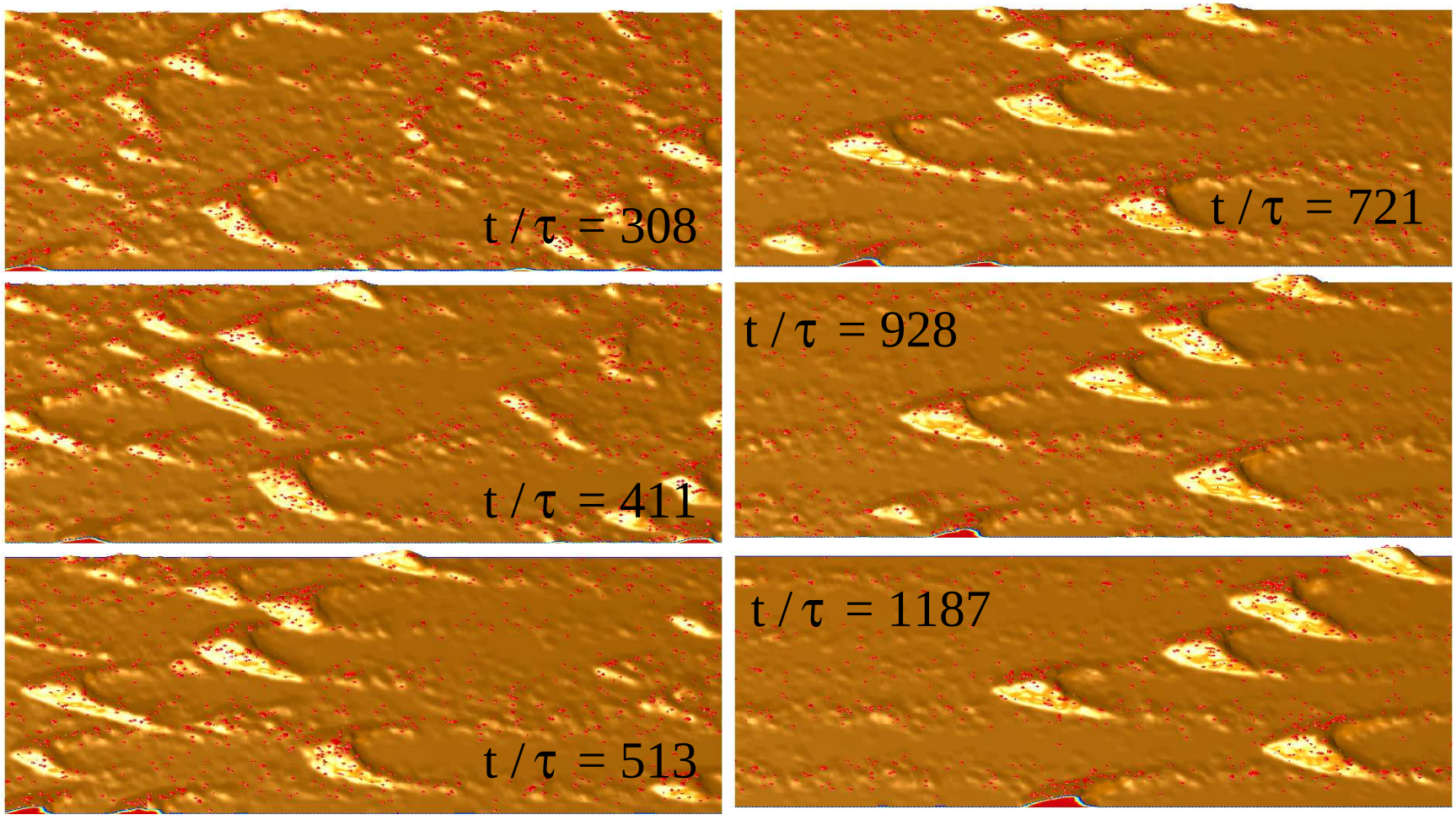

Flow
t / τ = 0
t / τ = 25
t / τ = 54
t / τ = 83
t / τ = 114
t / τ = 144
t / τ = 200
t / τ = 290

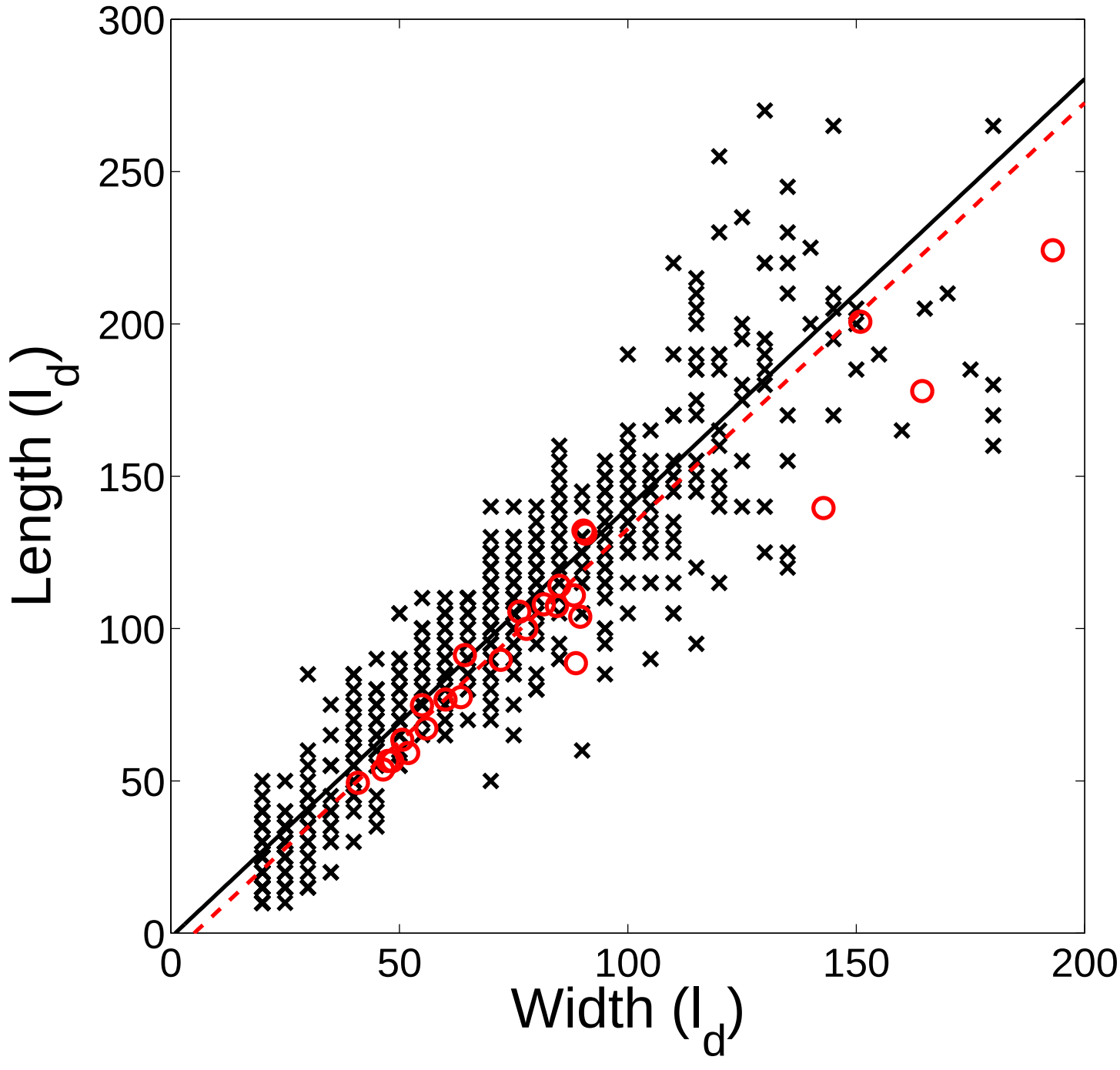

Width (η l_d)
Length (η l_d)
Heigth (l_d)
Distance
Time (τ)
width
length
65
60
55
50
45
40
35
30
25
20
15
10^2
10^3
10^4

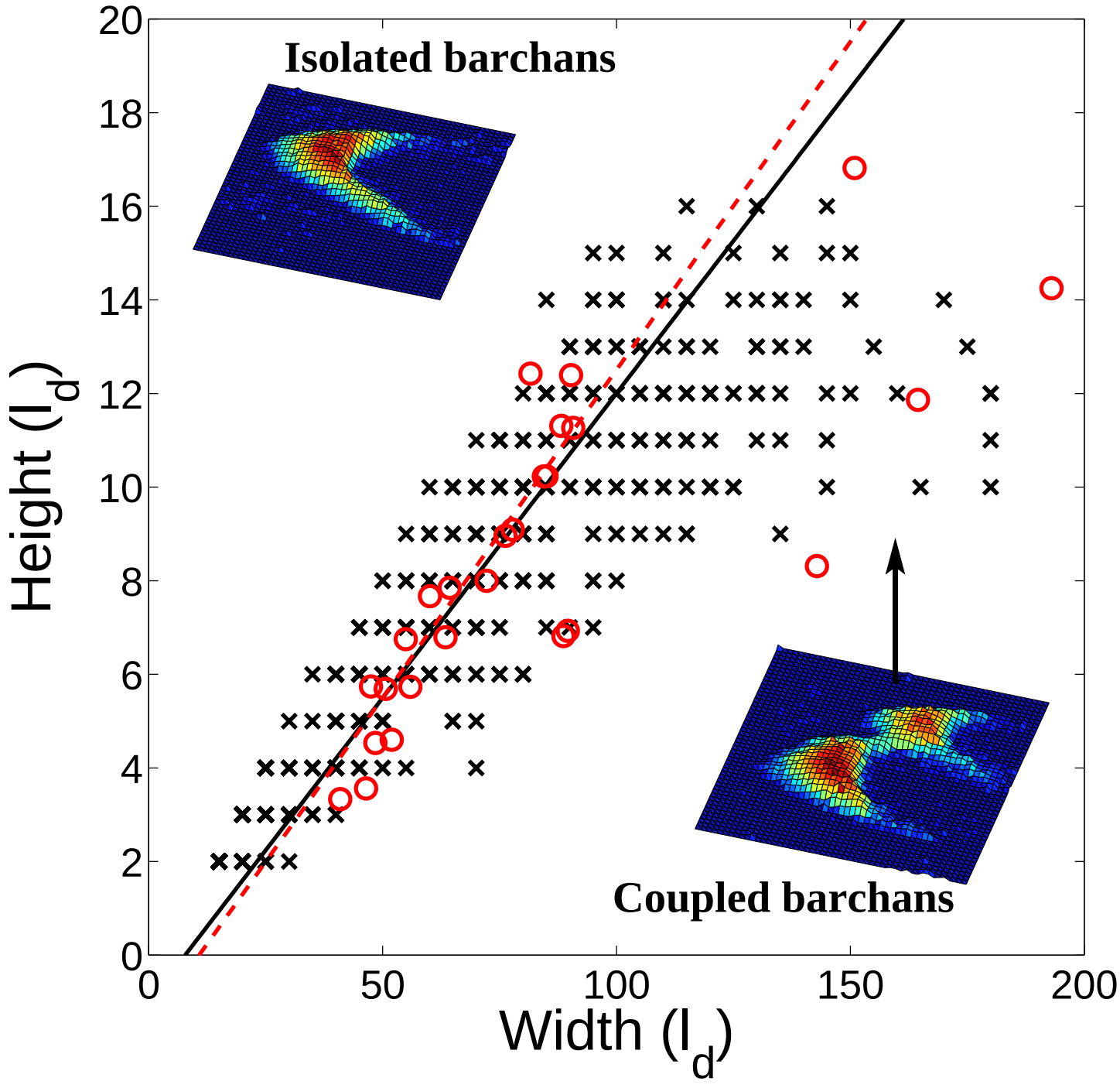

Distance (l_d)
10^3
10^2
10^1
10^1
10^2
10^3
Time (τ)
Distance (l_d)
1800
1600
1400
1200
1000
800
600
400
200
0
2000
4000
6000
8000
Time (τ)
Initial condition
stationnary state

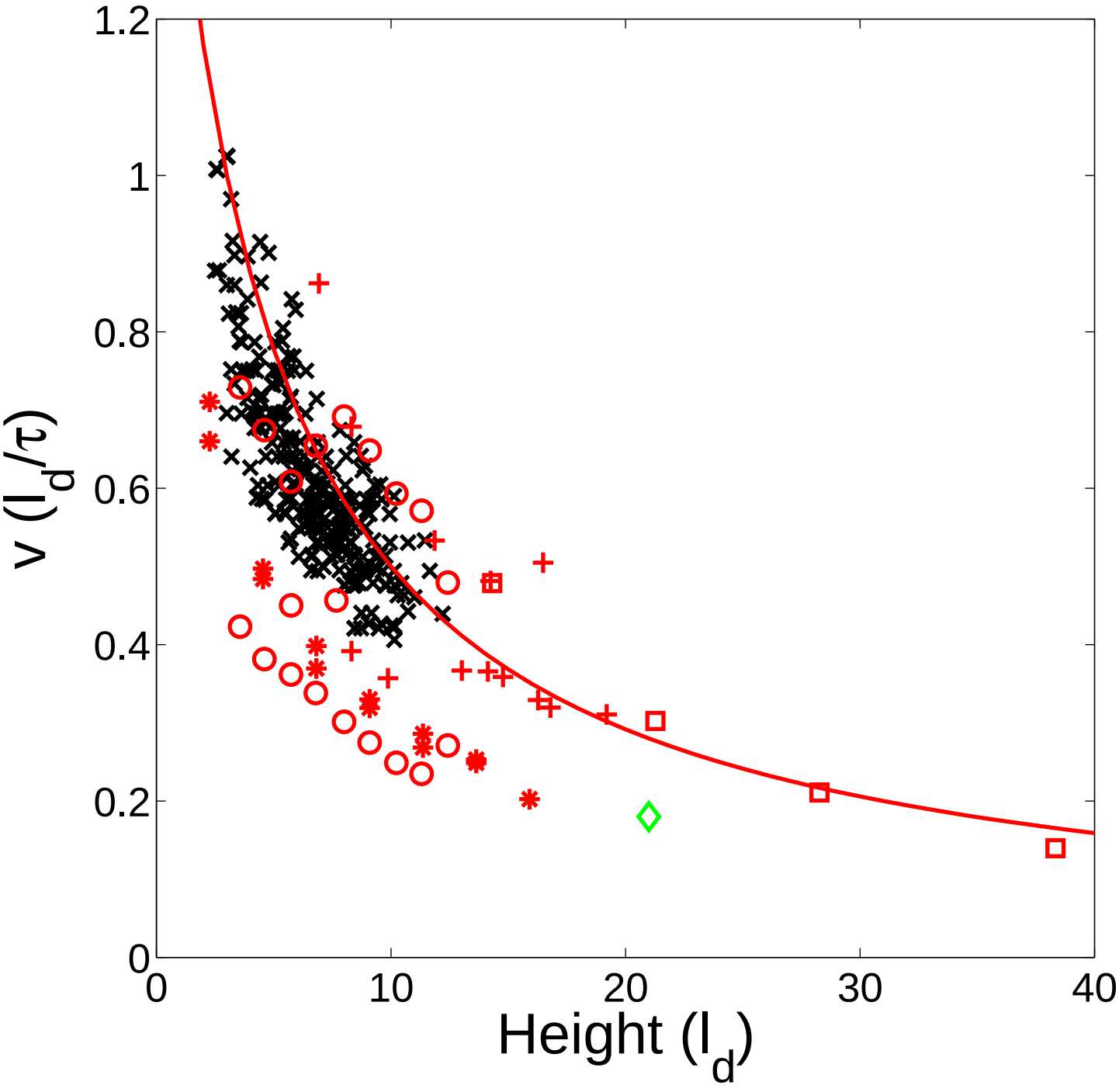

L
(a)
Wall
Grains
+ Fluid
Flow
Wall
(b)
Flow
(c)
Wall
Flow
Wall
L
H
H
Fluid flow
H
(a)
(b)
(c)


Flow
t / τ = 0
t / τ = 308
t / τ = 102
t / τ = 411
t / τ = 203
t / τ = 513

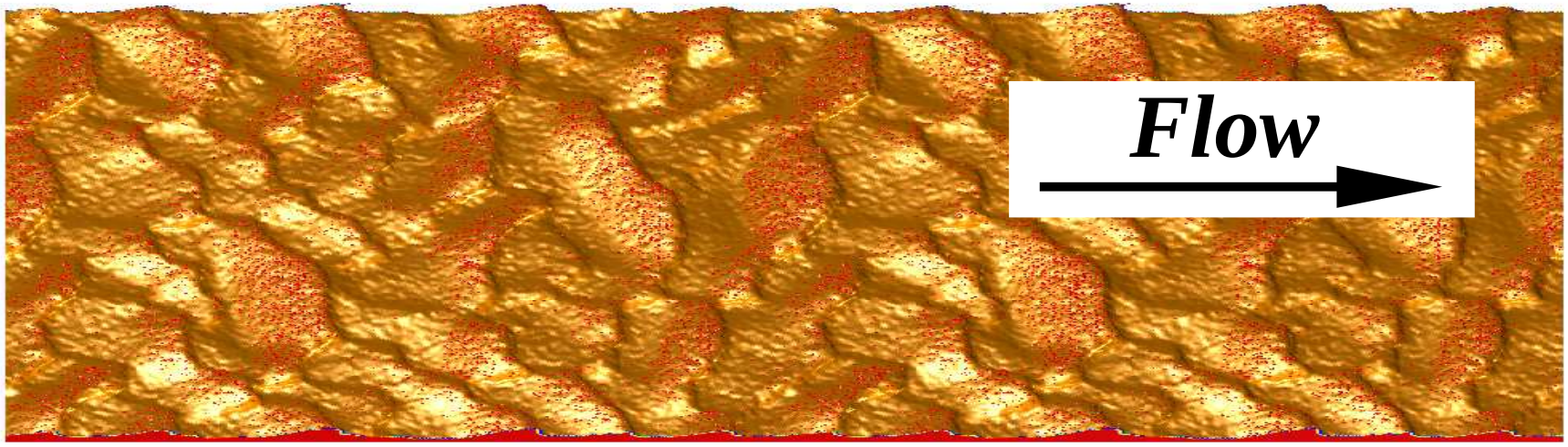

t / τ = 308
t / τ = 721
t / τ = 411
t / τ = 928
t / τ = 513
t / τ = 1187


300
250
200
150
100
50
0
0
50
100
150
200
Length (l_d)
Width (l_d)


Isolated barchans
Coupled barchans
Height (l_d)
Width (l_d)
0
2
4
6
8
10
12
14
16
18
20
0
50
100
150
200


1.2
1
0.8
0.6
0.4
0.2
0
v (l_d/τ)
0
10
20
30
40
Height (l_d)

Perspectives



Perspectives

Laboratory experiments
(Saint Maur, France)

Urümqi River (Tien Shan, China)