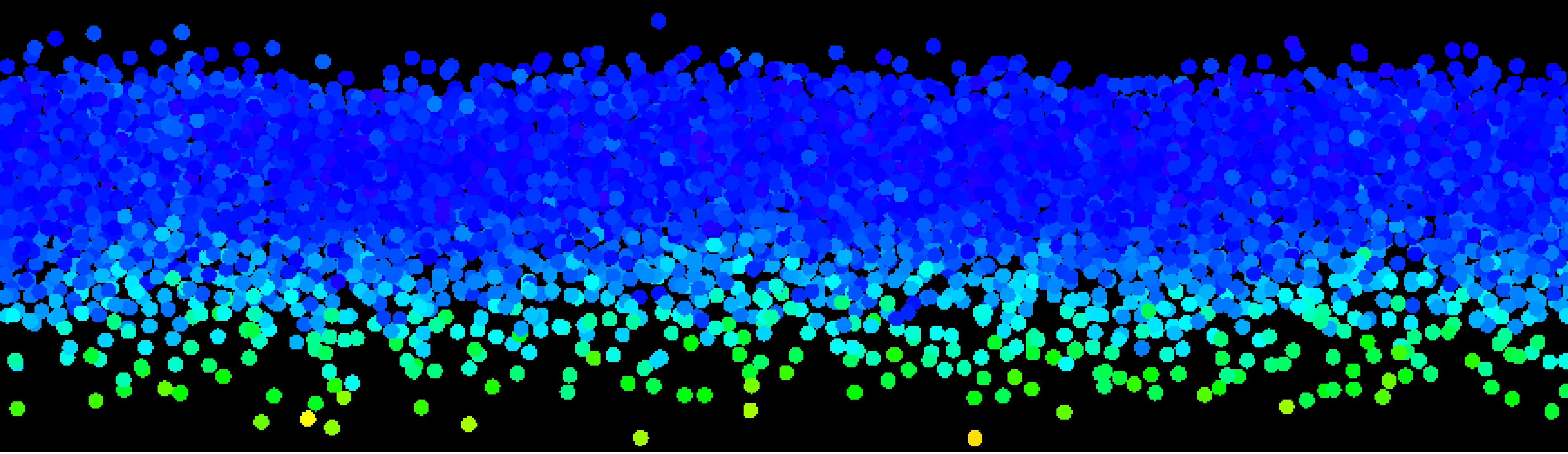
UNIVERSITY OF TWENTE.

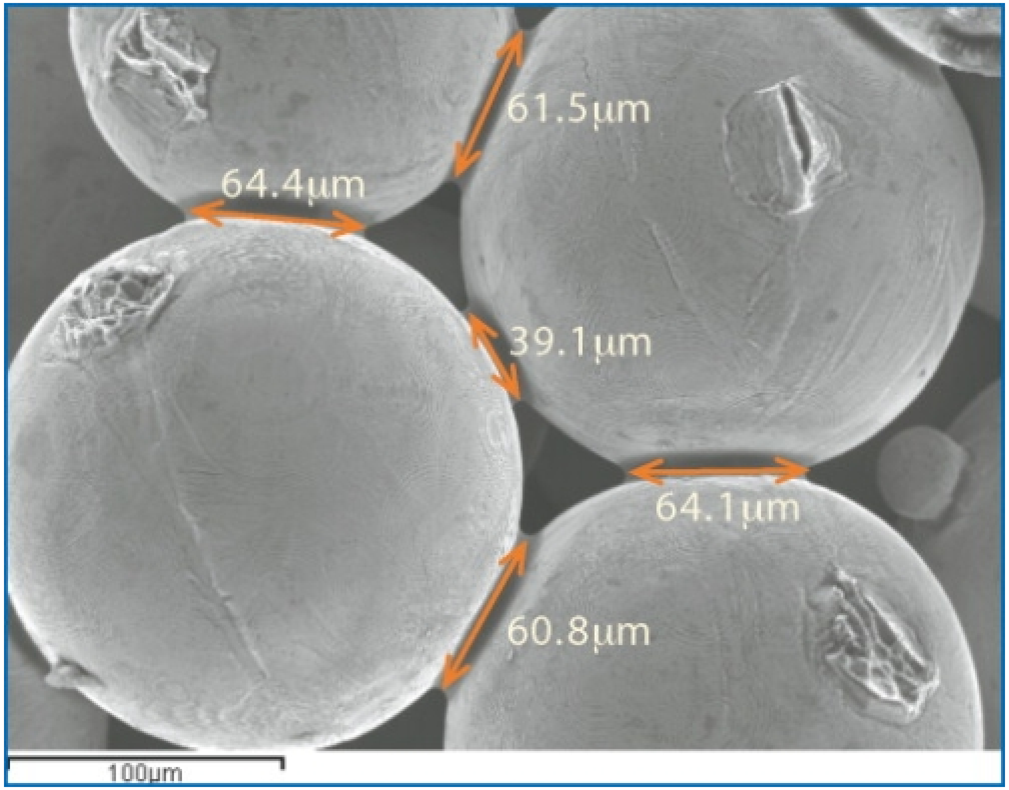
Multi Scale Mechanics (msm)

Nicolás Rivas, n.a.rivas@utwente.nl

FROM COLLIDING PARTICLES TO A HYDRODYNAMIC DESCRIPTION OF GRANULAR MATTER



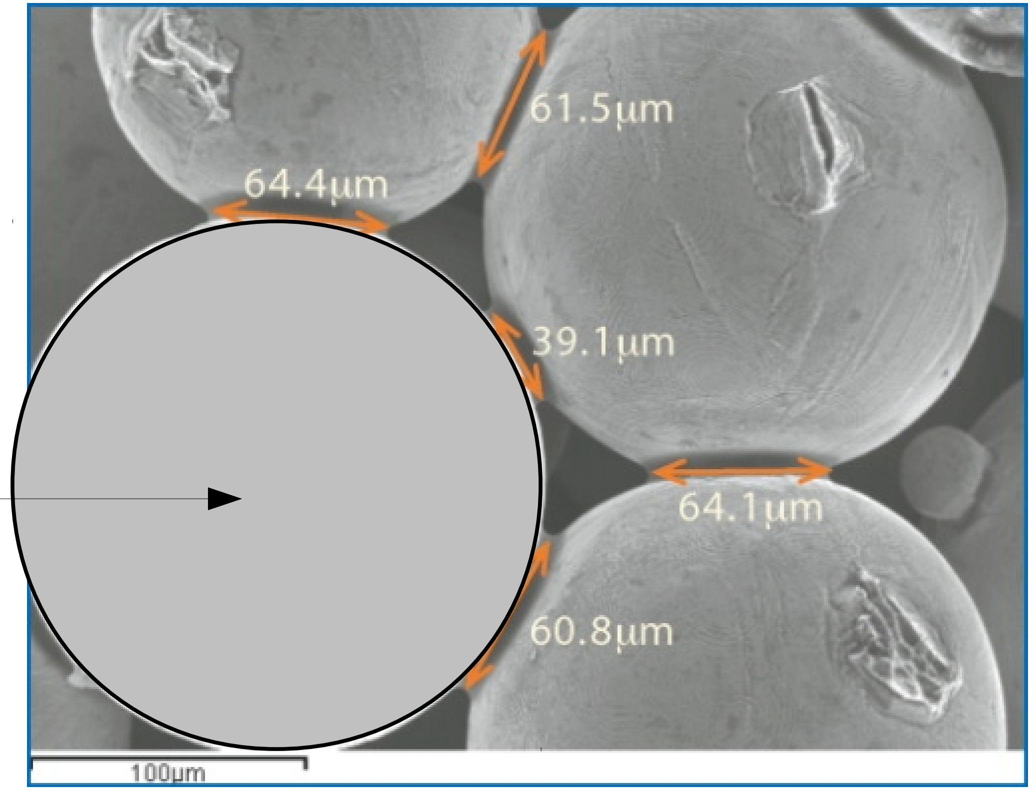
GRAINS



by *P. Imgrond et al.*

GRAINS

μ, ε
(μ_s, μ_d
ε_n, ε_t)



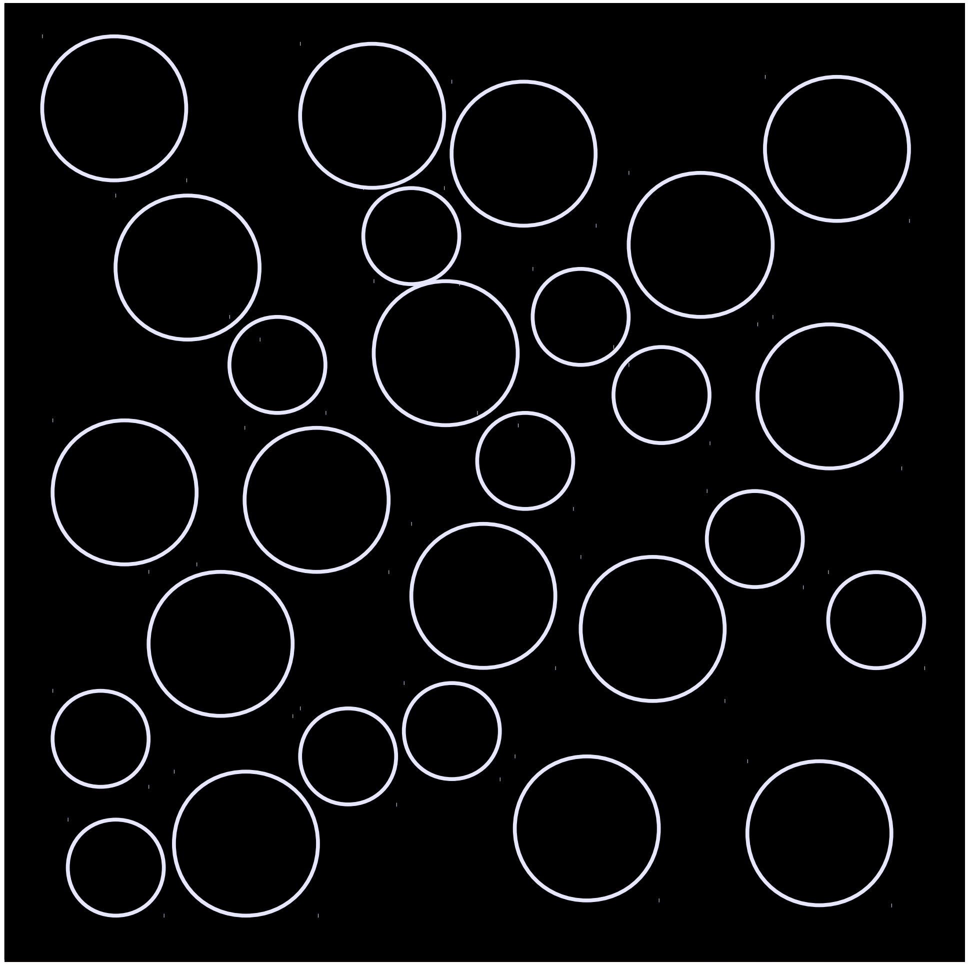
by *P. Imgrond et al.*

GRAINS

by *Dr. Gary Greenberg*

GRAINS

“size binary mixture”



CONTINUOUS MEDIUM

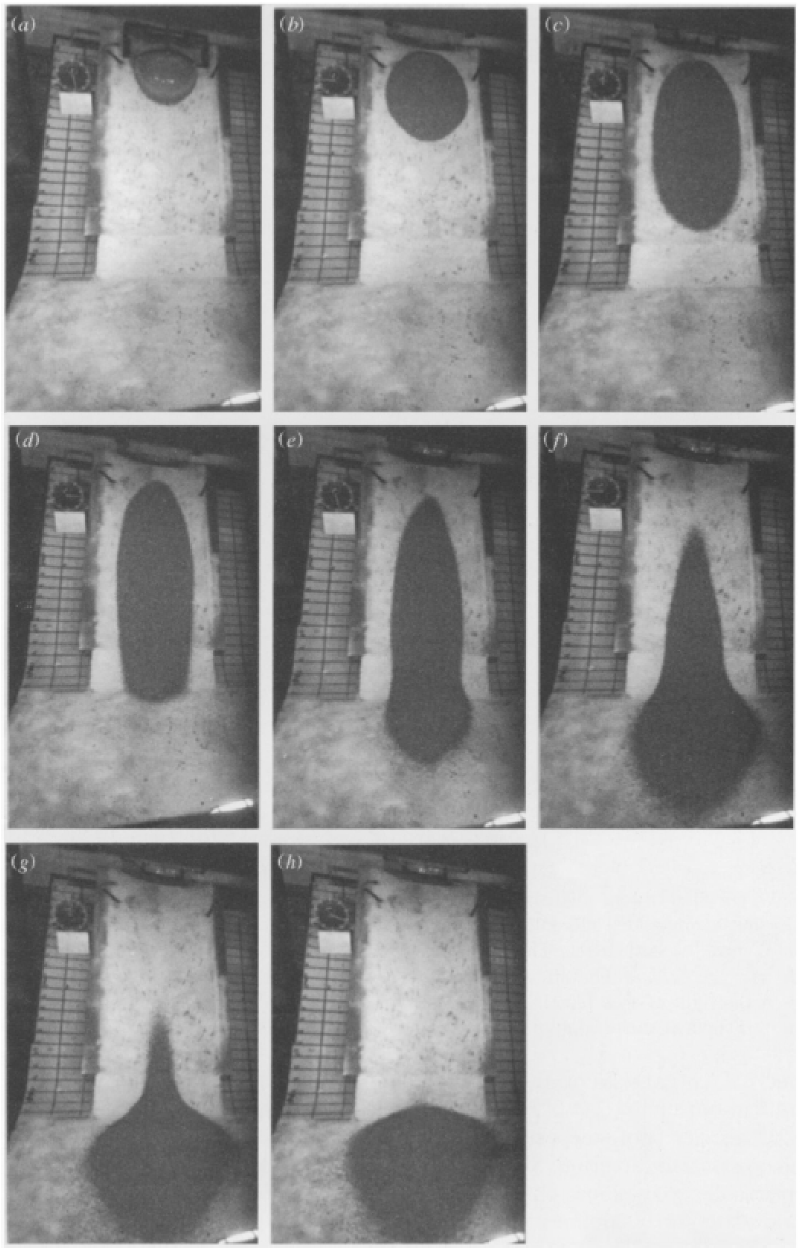
"...any small volume element in the fluid is always supposed so large that it still contains a <u>very great number</u> of molecules."

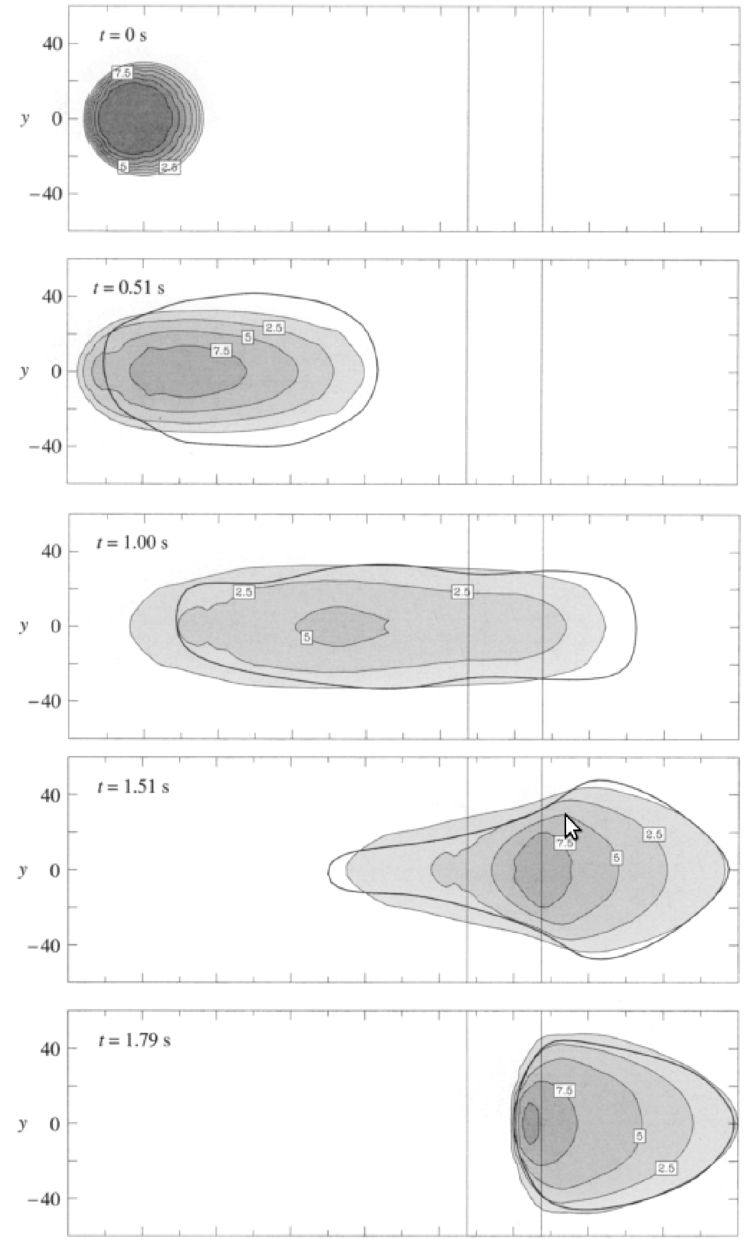
"...very small compared with the volume of the body under consideration, but large compared with the <u>distances</u> between the molecules."

—Fluid Mechanics, *L. D. Landau* and *E. M. Lifshitz*, p.1.

CONTINUOUS MEDIUM

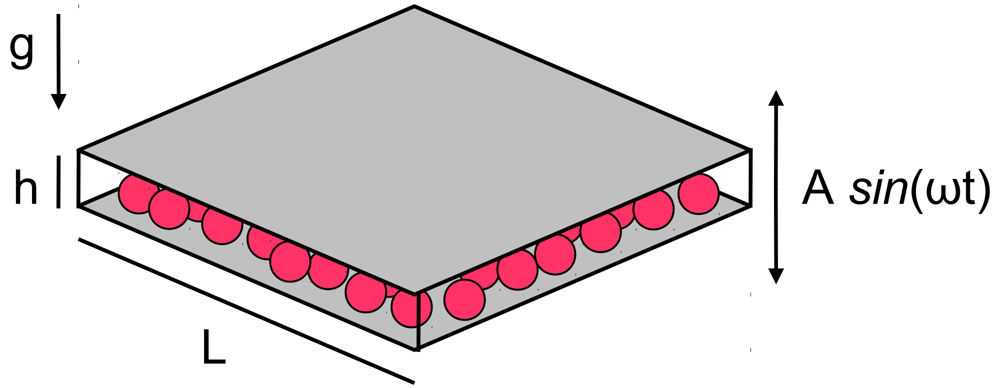
“From colliding particles to a hydrodynamic description of granular matter” N. Rivas

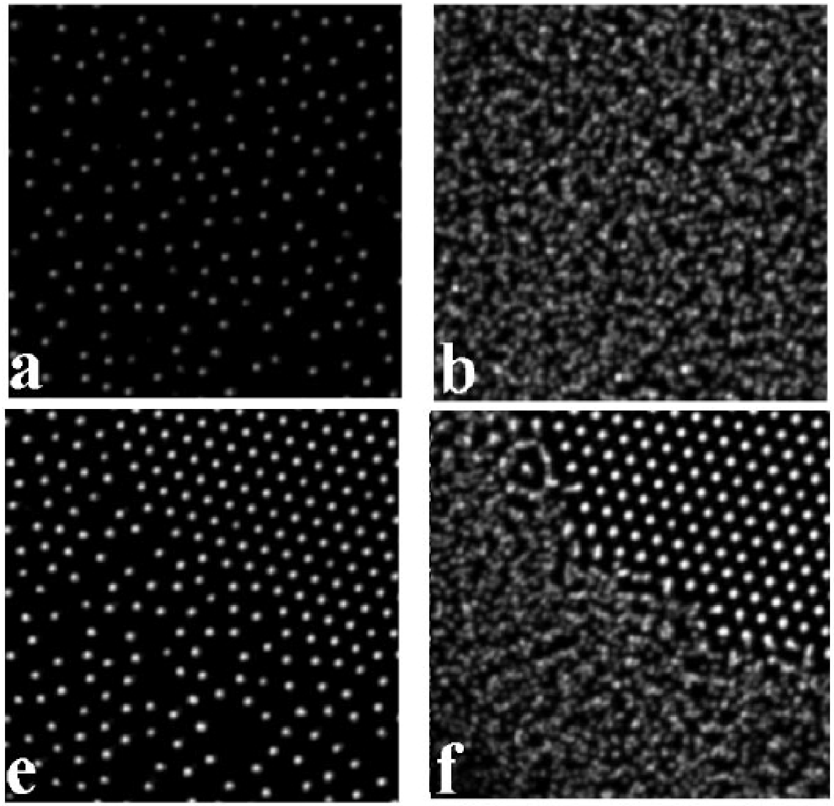




—*J. M. N. T. Gray, M. Wieland, K. Hutter*, 1998

VIBRATED BED





—*J. S. Olafsen et al.* Phys. Rev. Lett. 81, 4369-4372 (1998)

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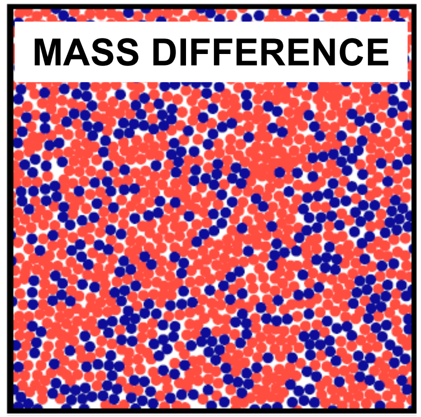
Binary Mixture



$N_A = 1000$

$N_B = 500$

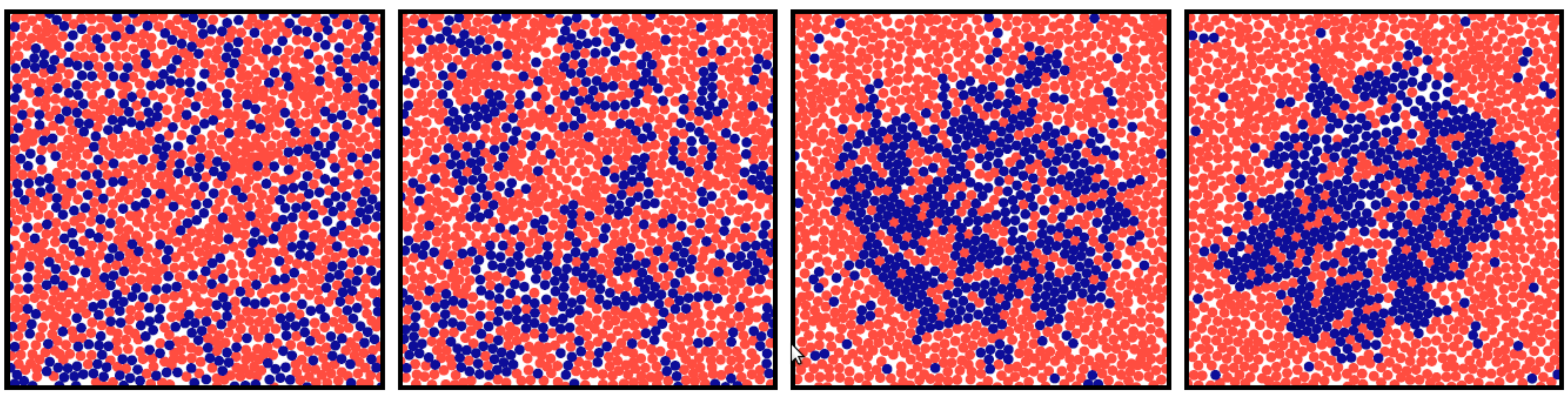
$\sigma_A = 1$

$\sigma_B \in (1,1.5)$

$m_A = 1$

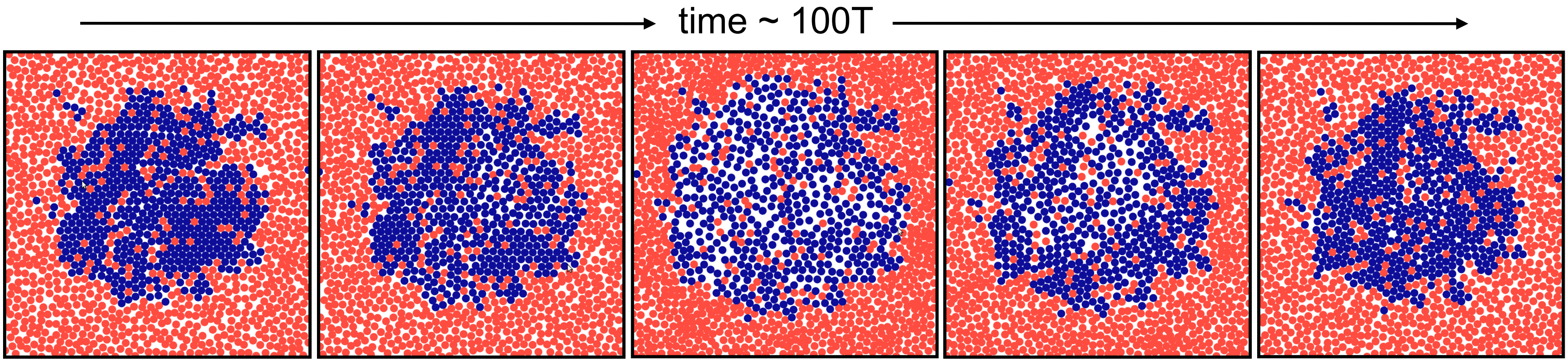
$m_B \in (1,10)$

INCREASING ω



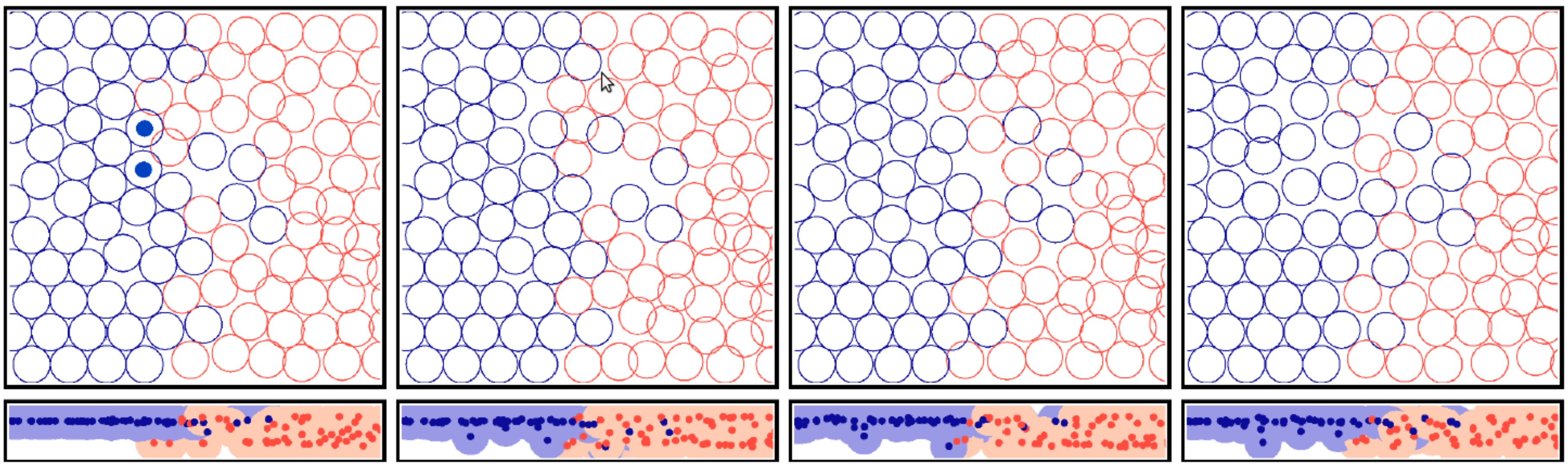
—*N. Rivas et al.* 2011 New J. Phys. 13 055018

VIBRATED BED



—*N. Rivas et al.* Phys. Rev. Lett. 106, 088001 (2011)

VIBRATED BED

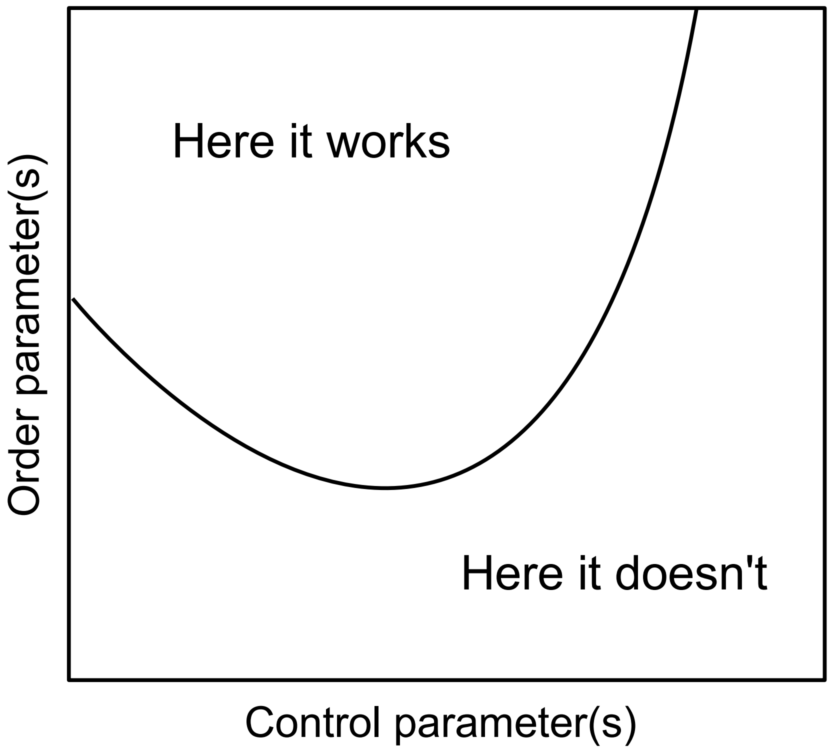


—*N. Rivas et al.* Granular Matter, 2012

Macroscopic consequences of microscopic phenomena

GOAL

GRANULAR HYDRODYNAMICS



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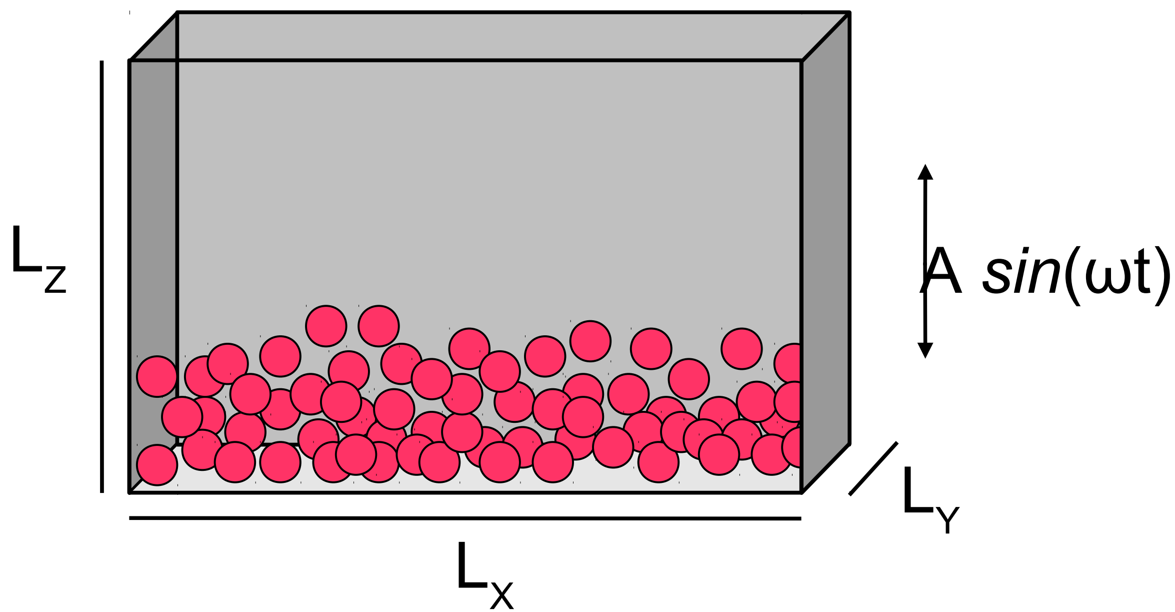

Quasi-2D: $L_Y << L_X \sim 100$

Number of particles, $N = 6000$

Dimensionless acceleration $\Gamma = A\omega^2/g \in (1,50)$

Low frequency $\omega \in (1,5)$, high amplitude $A \sim 4$

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FINGERING STATE

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LEIDENFROST STATE

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CONVECTIVE STATE

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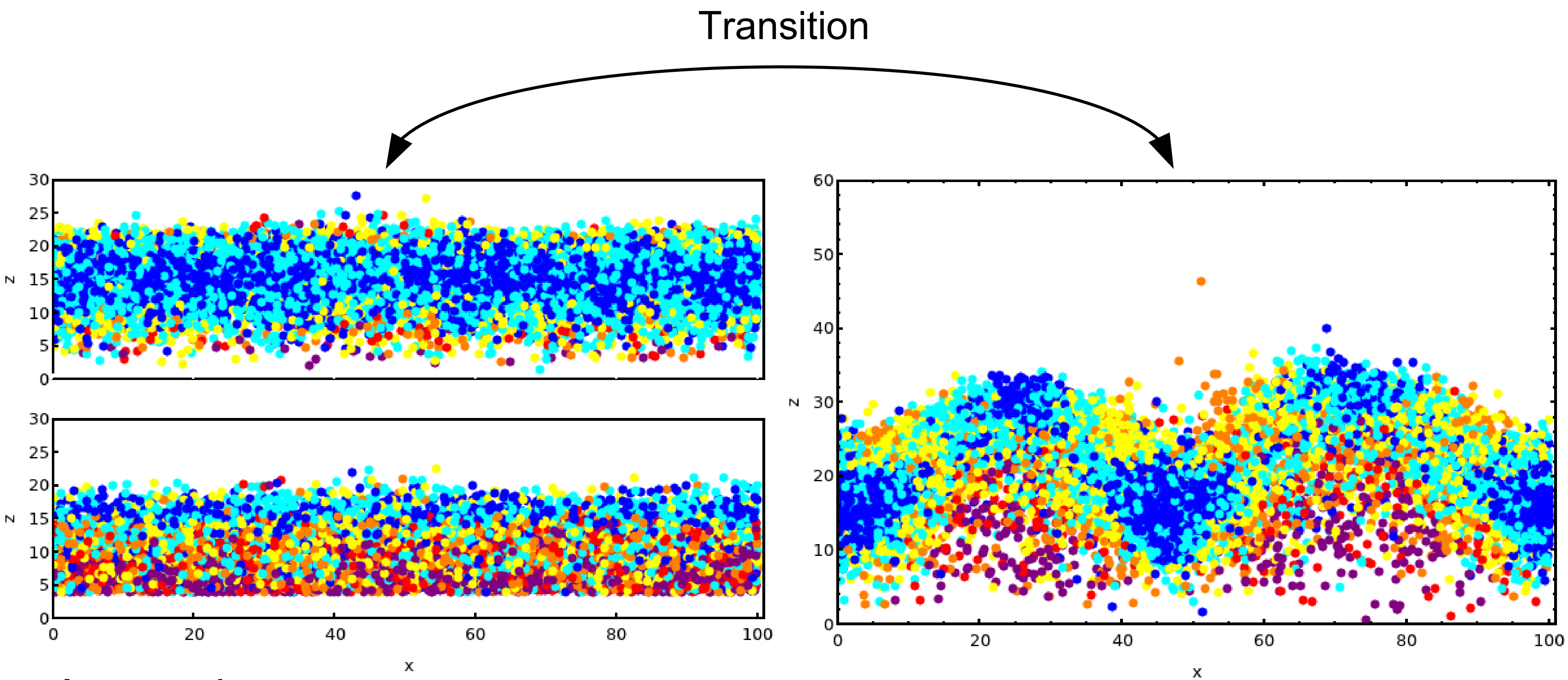

Approaches:

- Experimental
- Analytical
- Simulations:
  - Molecular Dynamics (ED, DEM)
  - Granular Hydrodynamics Solver

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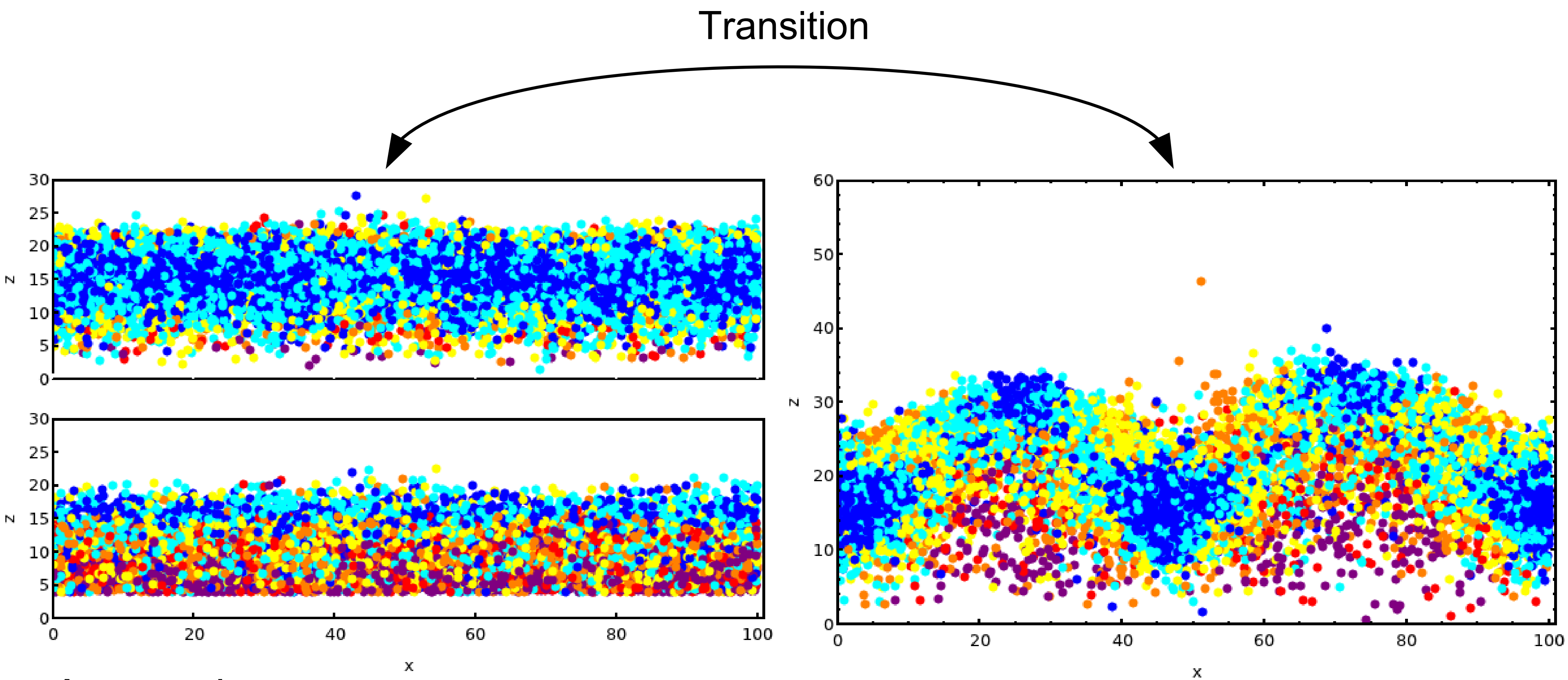

Approaches:

- Experimental
- Analytical
- Simulations:
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  - Granular Hydrodynamics Solver ⟵ Work in progress

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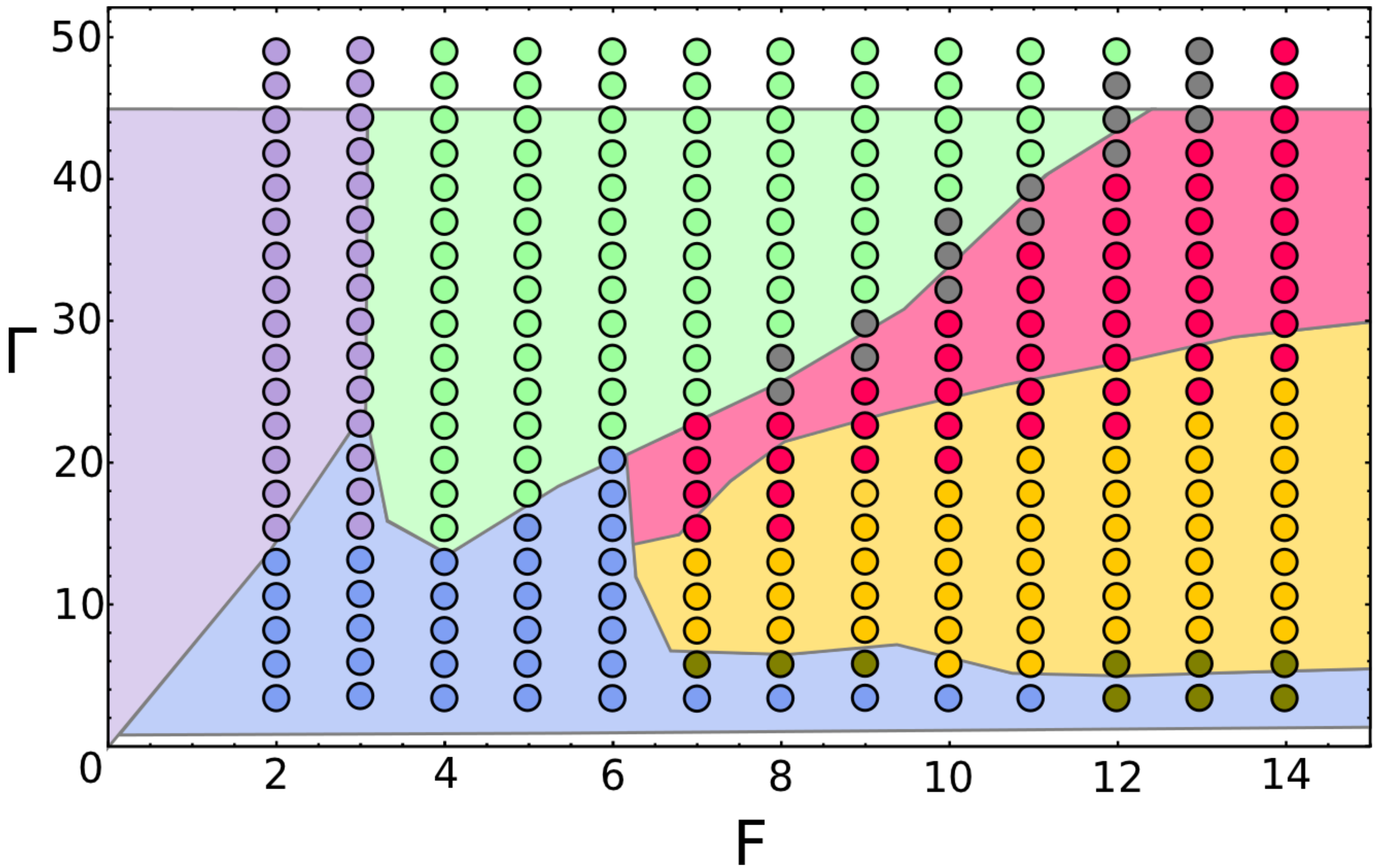
ED SIMULATIONS



—background from *P. Eshuis*, et al. Physics of Fluids, 2007

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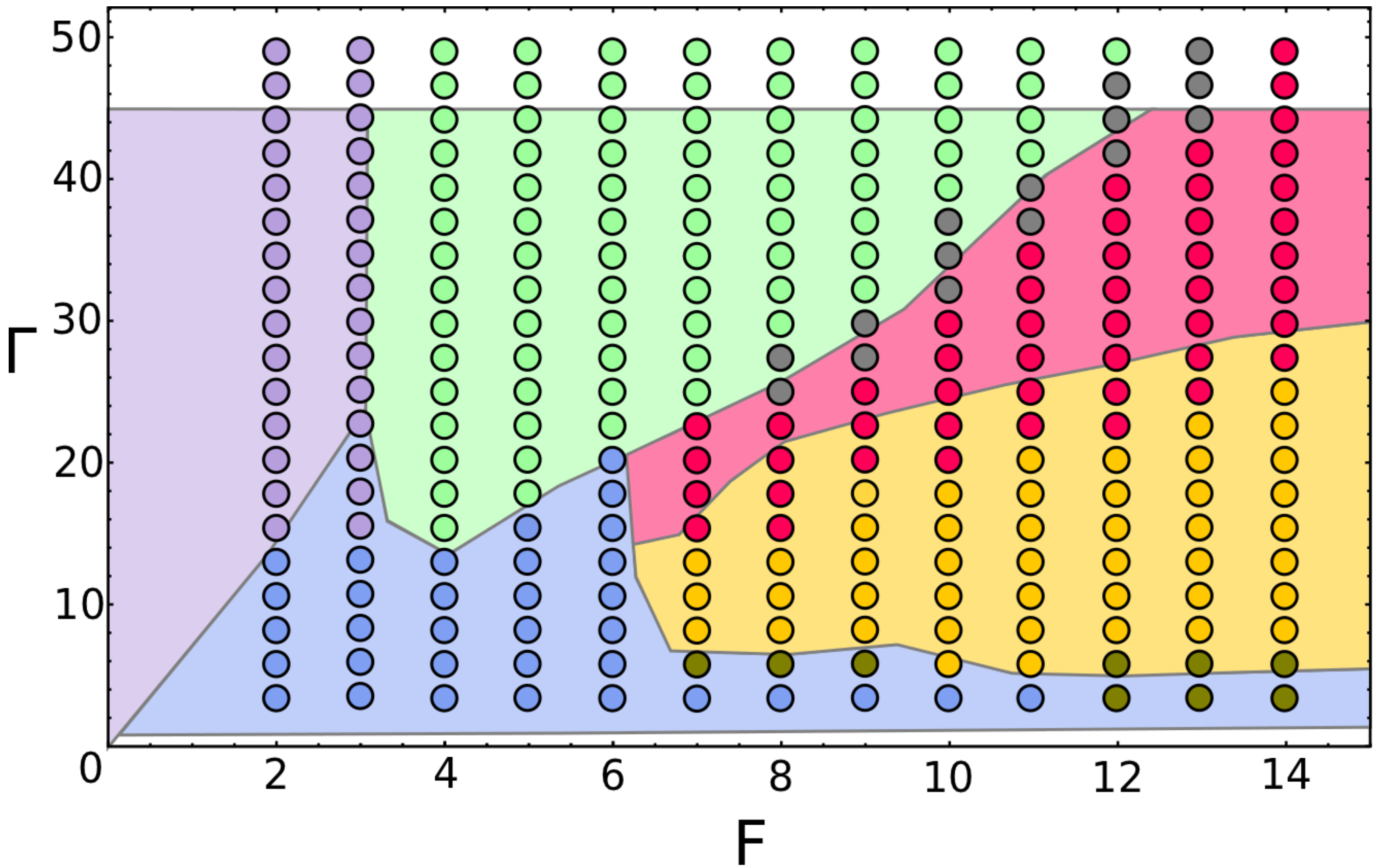
ED SIMULATIONS

ED is FAST → ALLOWS US TO EXPLORE PHASE SPACE



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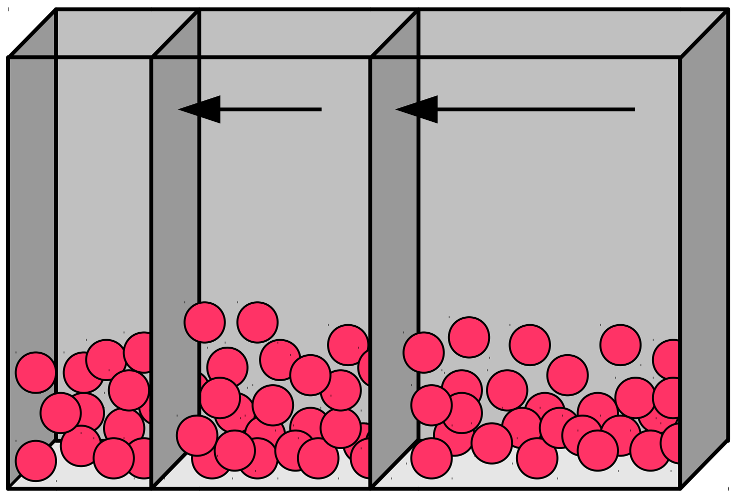
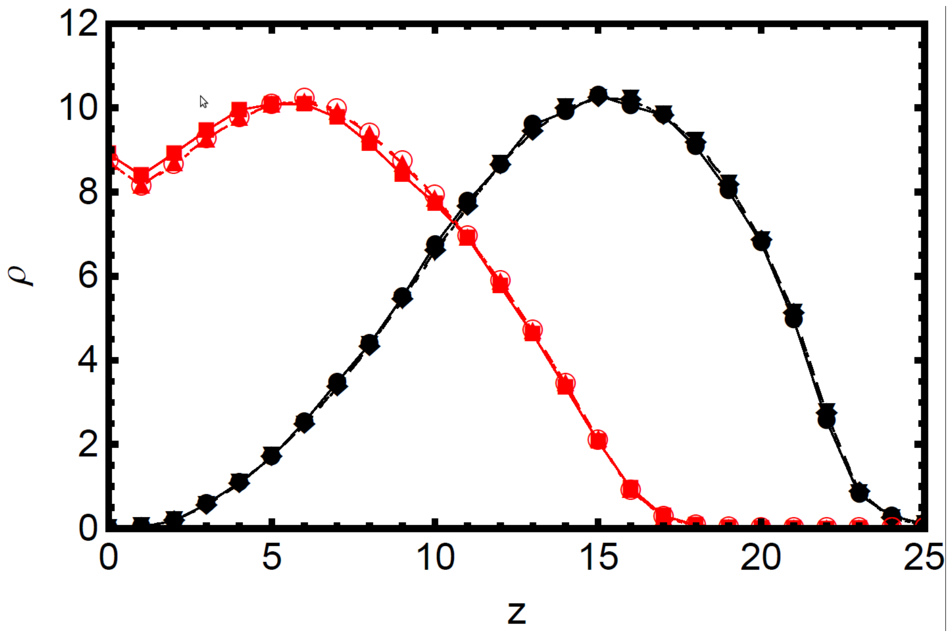
ED SIMULATIONS



VERTICAL DENSITY PROFILE



Lx = 10 solid,
Lx = 50 dashed,
Lx = 100 points

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ED SIMULATIONS

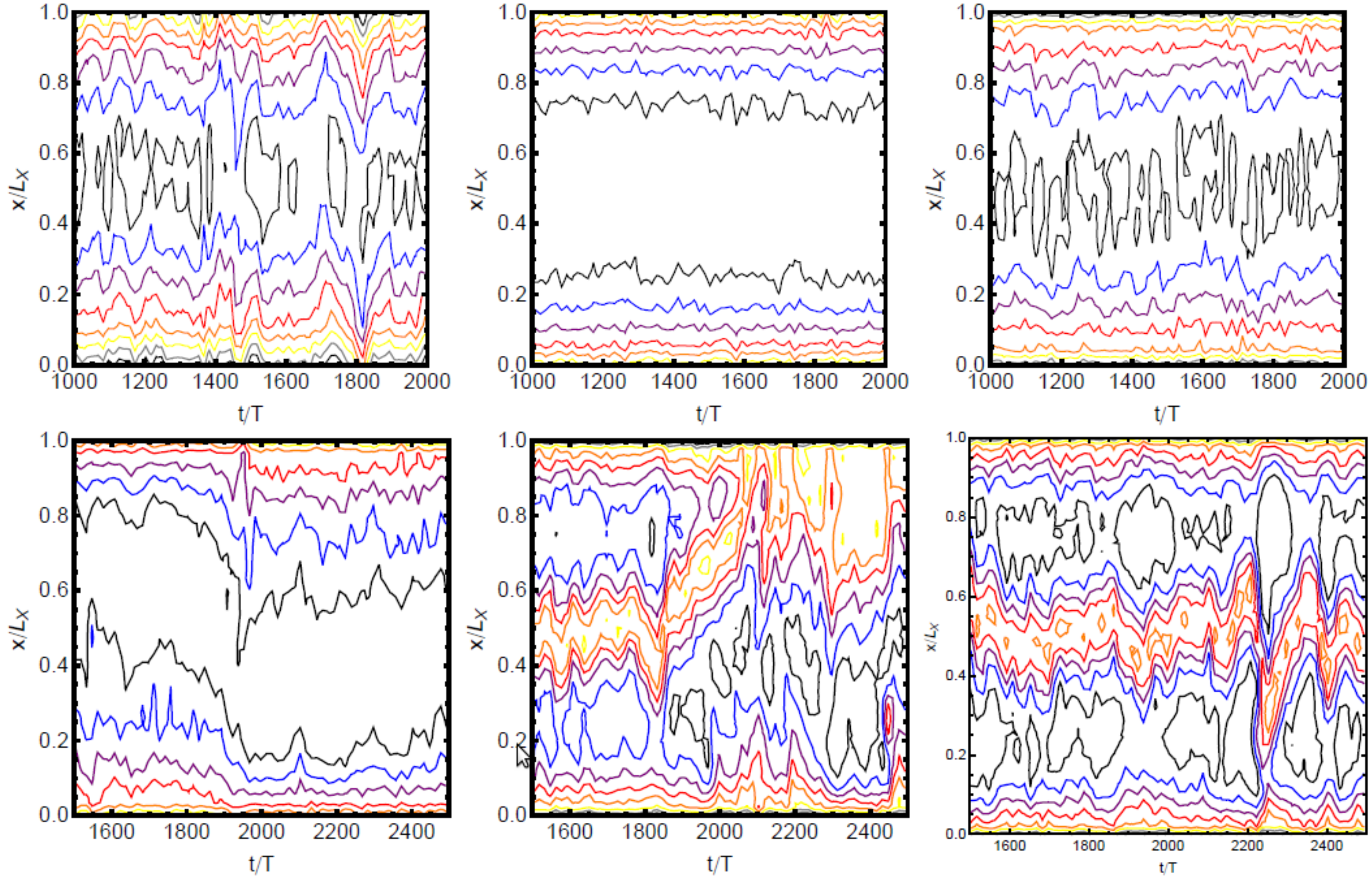

Figure 7: **Convection:** Several density spatio-temporal diagrams for different L_x. Black is low density. From top left to bottom right, $L_x = \{20, 40, 50, 60, 90, 100\}$

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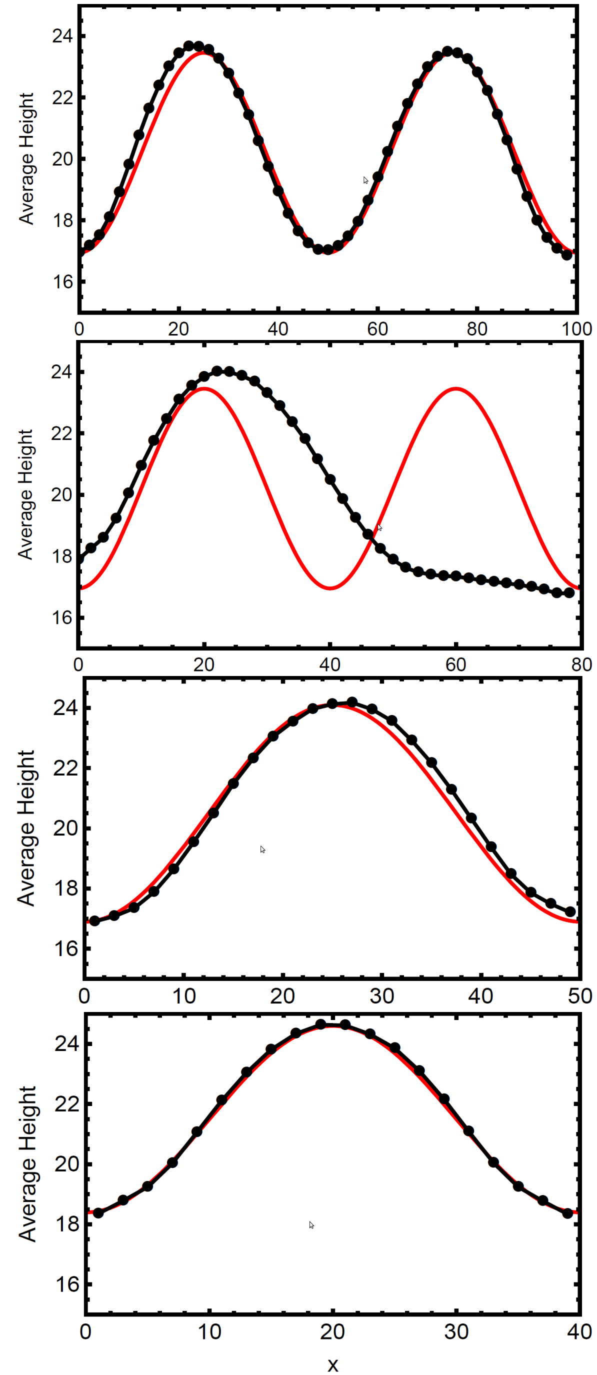
ED SIMULATIONS

$L_X = 100$

$L_X = 80$

$L_X = 50$

$L_X = 40$



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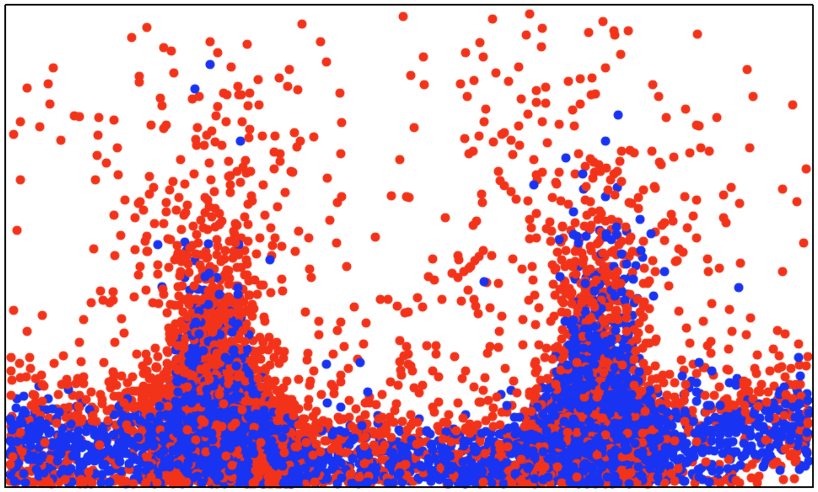
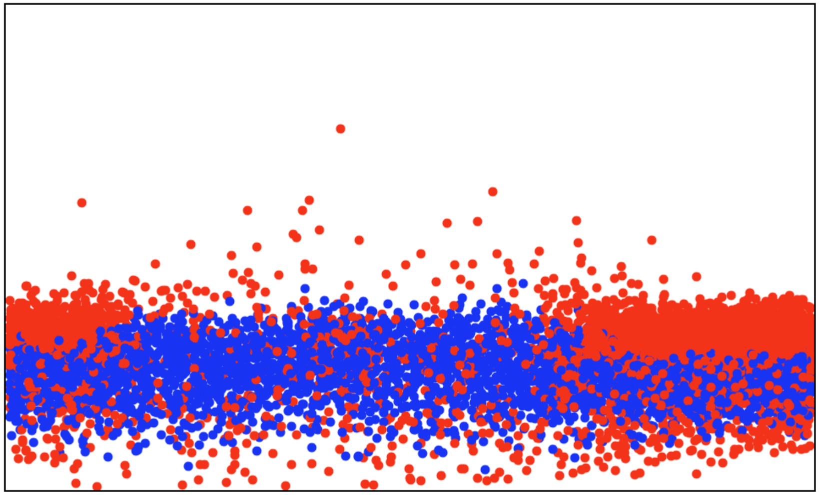
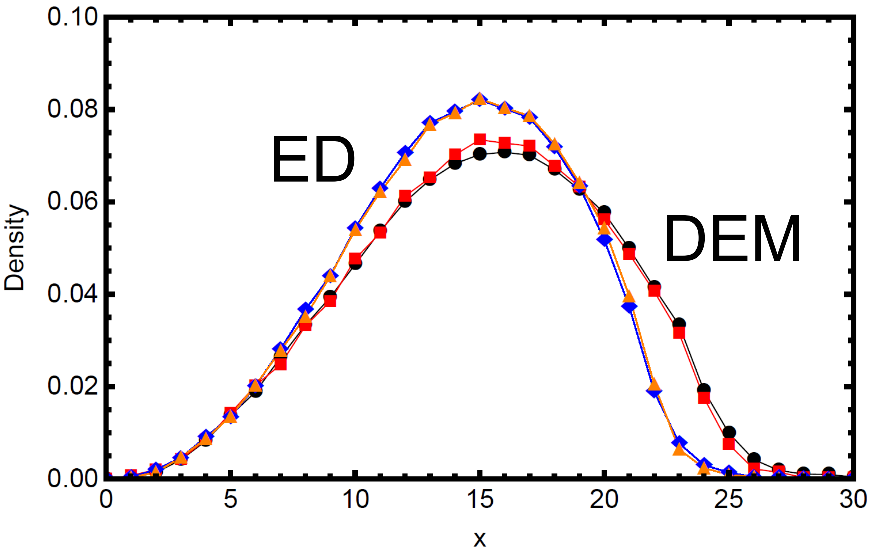
ED SIMULATIONS

Segregation with Binary Mixtures





Event Driven Discrete Element Comparison



FUTURE WORK

- Solve Granular Hydrodynamics equations:
  - Take part in the development of the differential equation solver software hpGEM.
- Further collaboration with experimental studies of the granular Leidenfrost effect, using ED simulations.
- Explore further the system phase space, using the speed advantage of ED simulations:
  - Study further the low frequency oscillations in the column geometry.
  - Explore the binary mixtures case, and try to explain the segregation with previously known mechanisms.