Vici Progress Report, March 2013.

Nicolás Rivas

Project description

Two general approaches are used to model granular materials: microscopic, where information is taken from individual particles, and macroscopic, where continuum fields are considered. In this project we apply and compare both approaches to a driven granular system, consisting in a vertically shaken shallow box filled with grains. This system presents many distinct inhomogeneous stable states as the energy injection, geometry, grain properties and grains number are varied. Studying the stability of these states and the transitions between them, from both a microscopic and macroscopic approach, may lead to a better understanding of the out-of-equilibrium statistical physics behind complex granular systems. We also focus on the development and comparison of a set of simulation tools, both microscopic (molecular dynamics) and macroscopic (granular-hydrodynamics equations solver), to establish the limits and advantages of each approach in different scenarios.

Recent papers

- *Sudden chain energy transfer events in vibrated granular media*
  N Rivas, S Ponce, B Gallet, D Risso, R Soto, P Cordero, N Mujica
  Physical Review Letters 106 (8), 88001

In a mixture of two species of grains of equal size but different mass, placed in a vertically vibrated shallow box, there is spontaneous segregation. Once the system is at least partly segregated and clusters of the heavy particles have formed, there are sudden peaks of the horizontal kinetic energy of the heavy particles, that is otherwise small.

- *Segregation in quasi-two-dimensional granular systems*
  N Rivas, P Cordero, D Risso, R Soto
  New Journal of Physics 13, 055018

Segregation for two granular species is studied numerically in a vertically vibrated quasi-two-dimensional (quasi-2D) box.

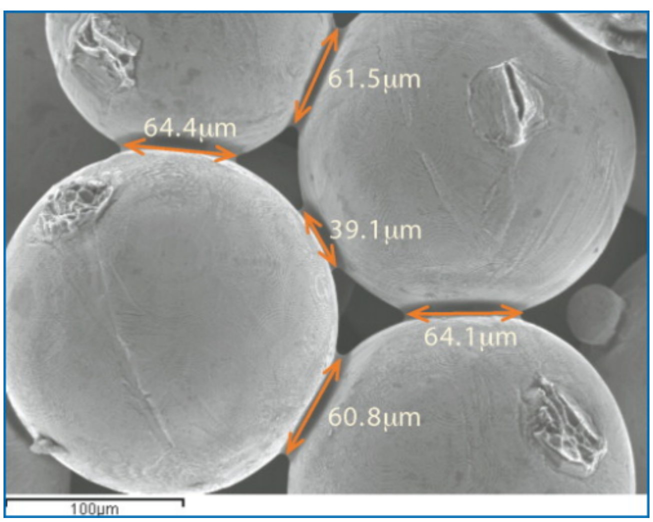
Recent talk

Nicolás Rivas (n.a.rivas@utwente.nl)

October 10, 2012

Low-frequency oscillations in vertically vibrated granular beds

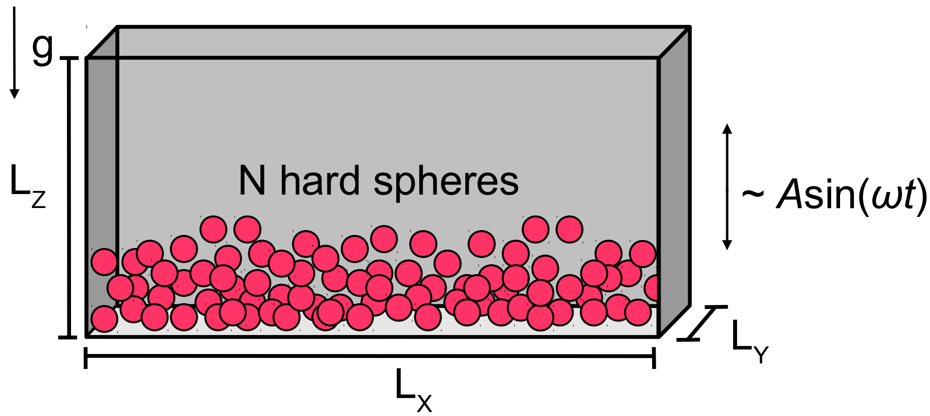
GRAINS



by *P. Imgrond et al.*

SYSTEM GEOMETRY

"Low-frequency oscillations in vertically vibrated granular beds"
N. Rivas, MSM, University of Twente



Quasi-two-dimensional geometry:

$L_y = 5$

$L_X \in (5,100)$

Number of particles: $F \equiv N/LxLy = 12$

Dimensionless speed: $S \equiv A^2\omega^2/gd \in (XXX,XXX)$

SYSTEM GEOMETRY

"Low-frequency oscillations in vertically vibrated granular beds"
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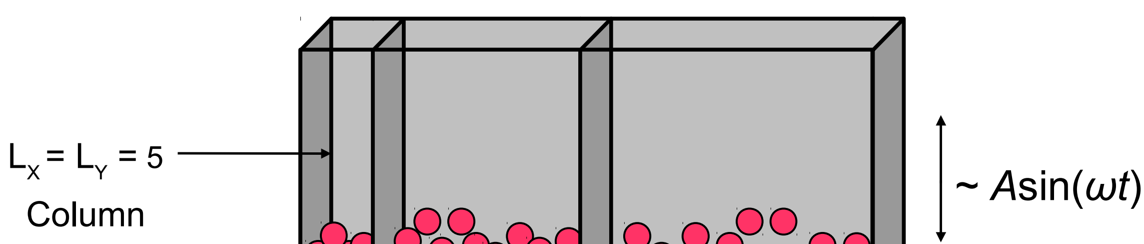
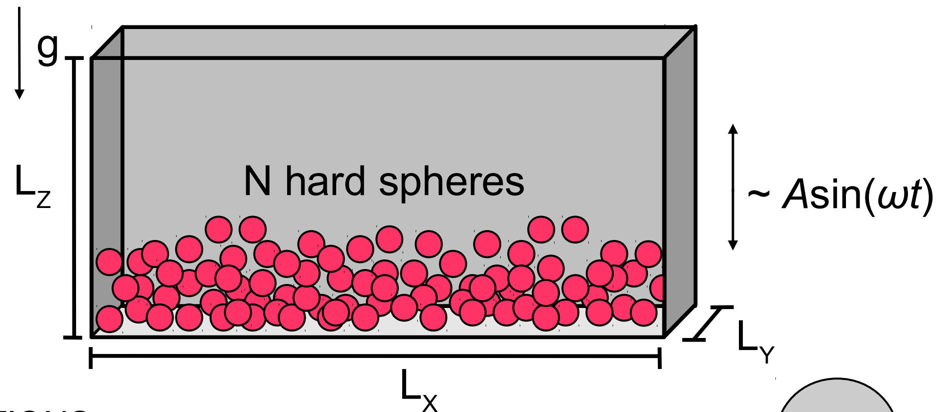


OUTLINE

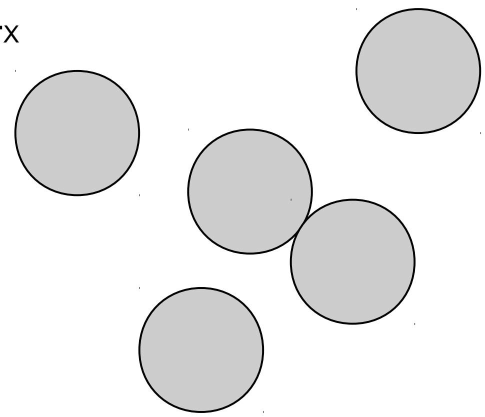
+ Wide geometry: previous research
+ Decrease system length
+ Column geometry: low-frequency oscillations (LFOs)
+ Possible influence on wide system

SIMULATIONS



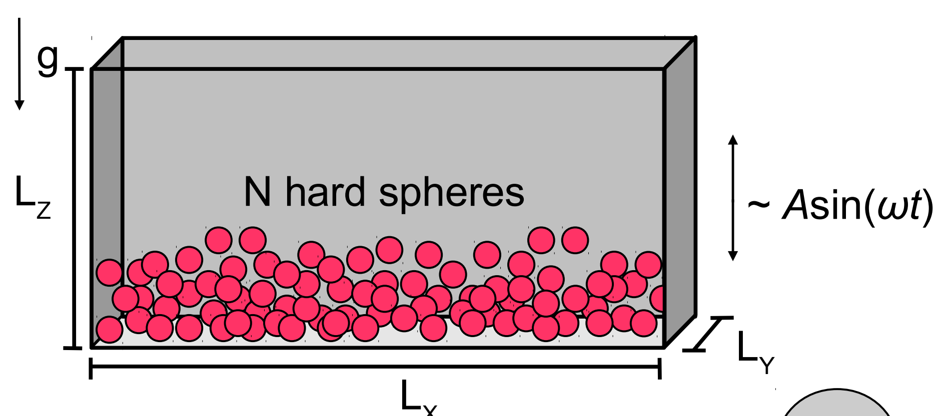
SIMULATIONS

+ Event-driven simulations.
+ Perfect hard spheres.
+ Collisions given by μ_S, μ_D, ε_N, ε_T
+ Solid boundary conditions.
+ Bi-parabolic sine interpolation.



"Low-frequency oscillations in vertically vibrated granular beds"
N. Rivas, MSM, University of Twente

SIMULATIONS



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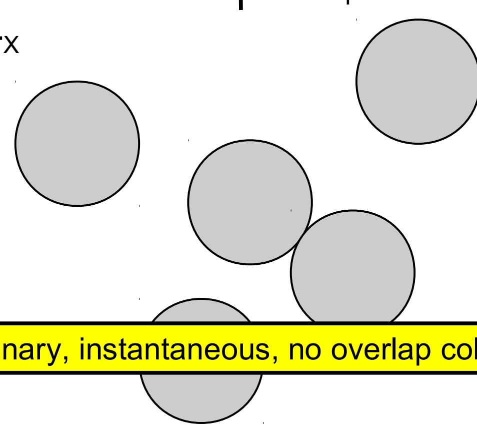


Binary, instantaneous, no overlap collisions.

UNDULATIONS

F = 12, ω = 2, A = 4

* Color corresponds to kinetic energy

STATES

"Low-frequency oscillations in vertically vibrated granular beds"
N. Rivas, MSM, University of Twente

LEIDENFROST STATE

F = 12, ω = 7, A = 1

* Color corresponds to kinetic energy

STATES

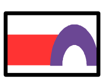
CONVECTIVE STATE

F = 12, ω = 10, A = 1.0

* Color corresponds to kinetic energy

STATES

"Low-frequency oscillations in vertically vibrated granular beds"
N. Rivas, MSM, University of Twente

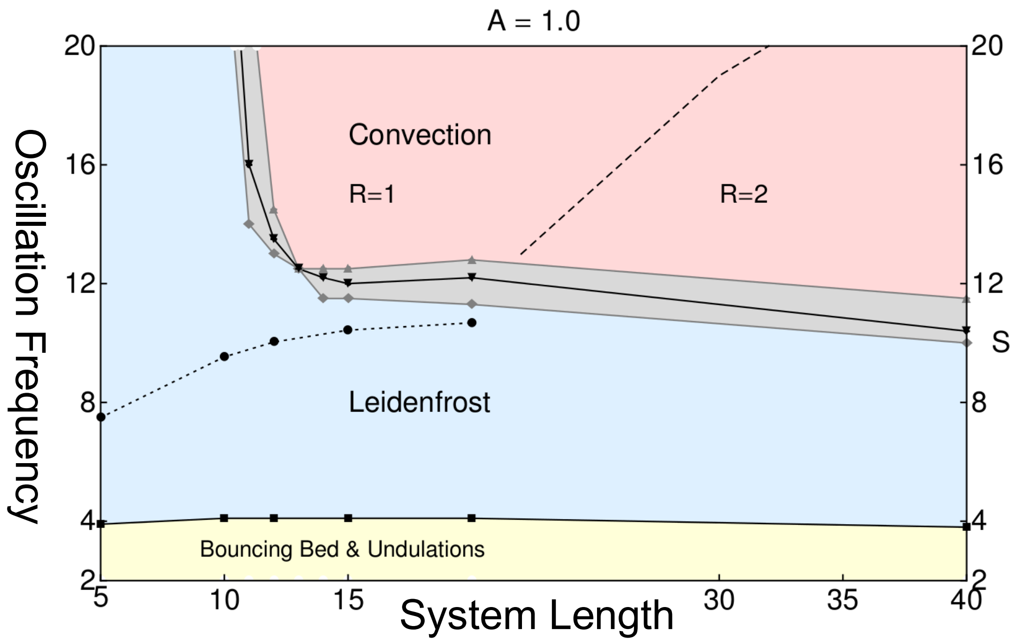


LEIDENFROST STATE?

F = 12, ω = 9, A = 1

* Color corresponds to kinetic energy

PHASE DIAGRAM



INTERMEDIATE

"Low-frequency oscillations in vertically vibrated granular beds"
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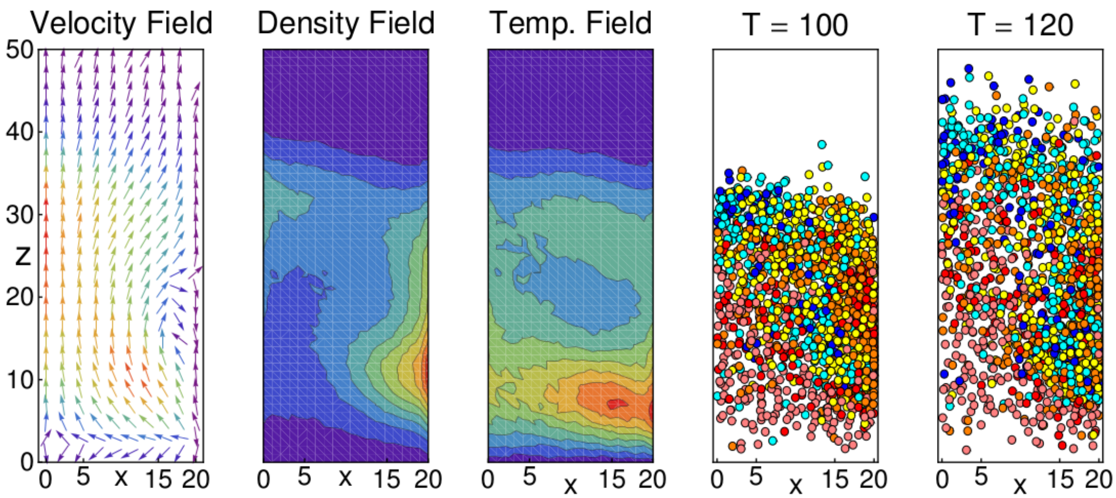
F = 12, ω = 10, A = 1

L_x = 20

FIELDS



COLUMN

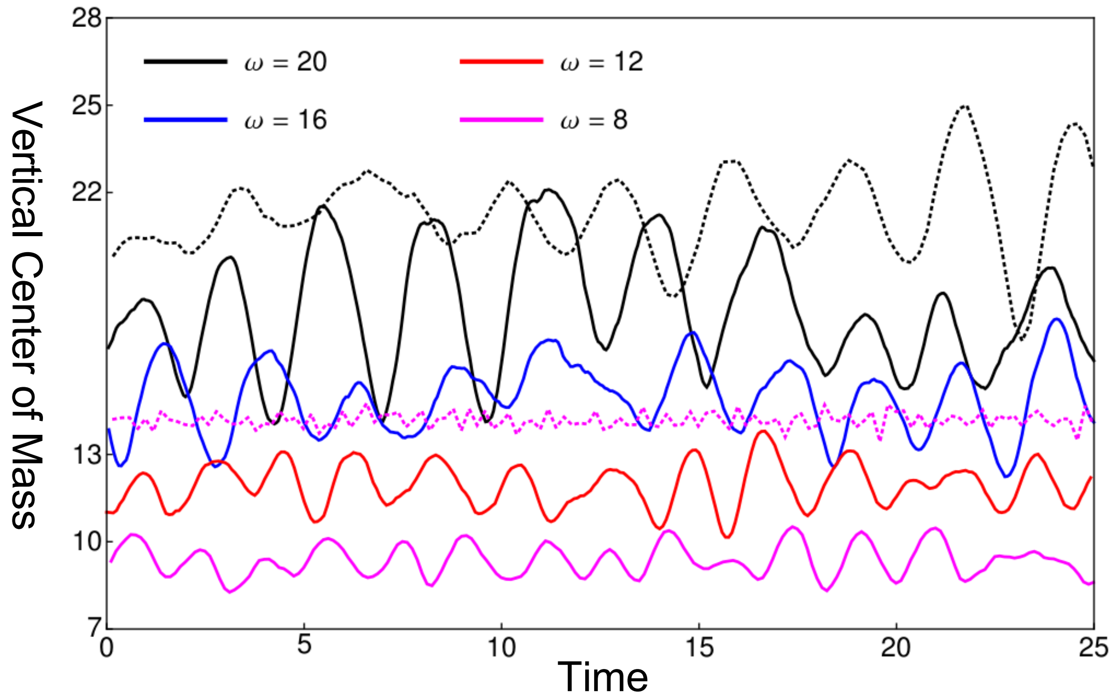
"Low-frequency oscillations in vertically vibrated granular beds"
N. Rivas, MSM, University of Twente

$F = 12, \omega = 10, A = 1$

$L_X = 5$

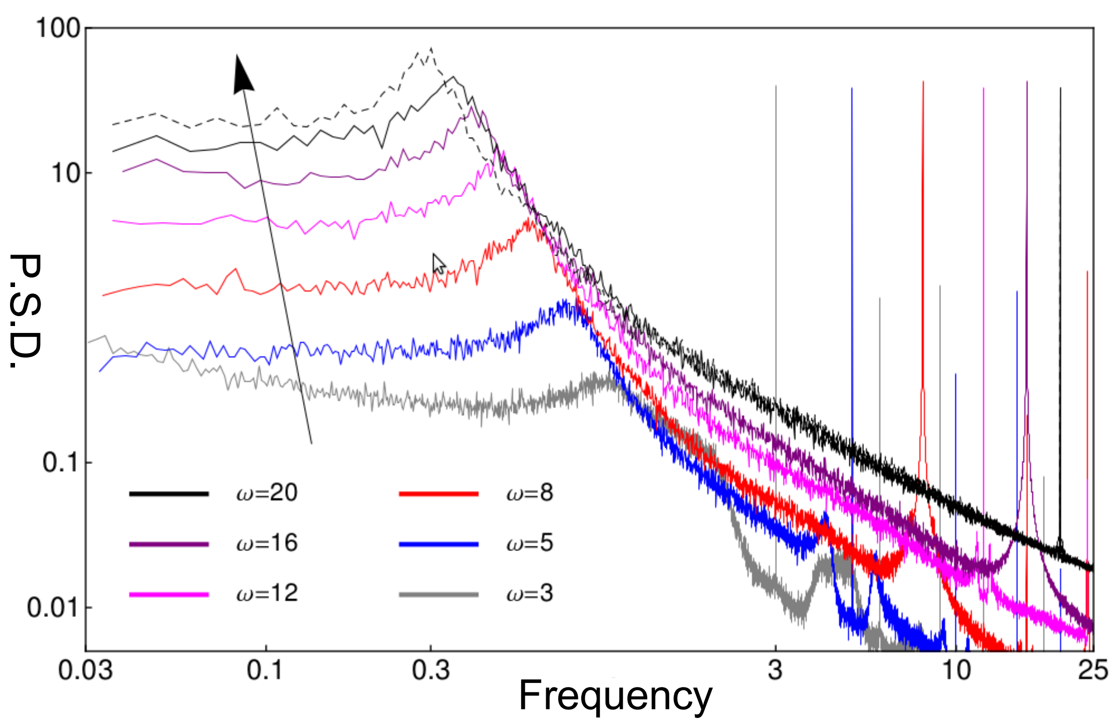
COLUMN: LFOs

“Low-frequency oscillations in vertically vibrated granular beds”
N. Rivas, MSM, University of Twente



COLUMN: LFOs

“Low-frequency oscillations in vertically vibrated granular beds”
N. Rivas, MSM, University of Twente



COLUMN: LFOs

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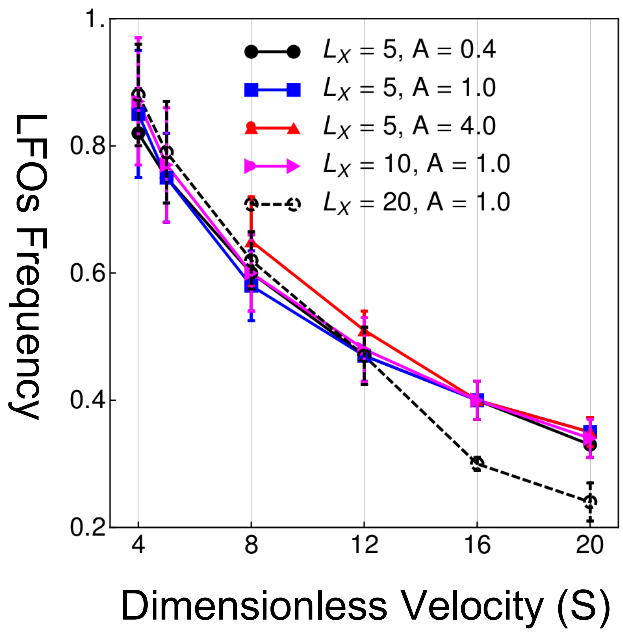

COLUMN: LFOs

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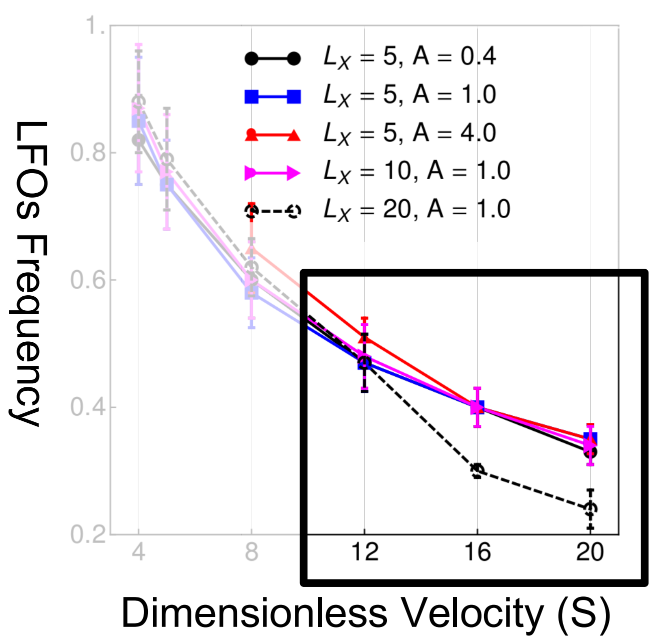
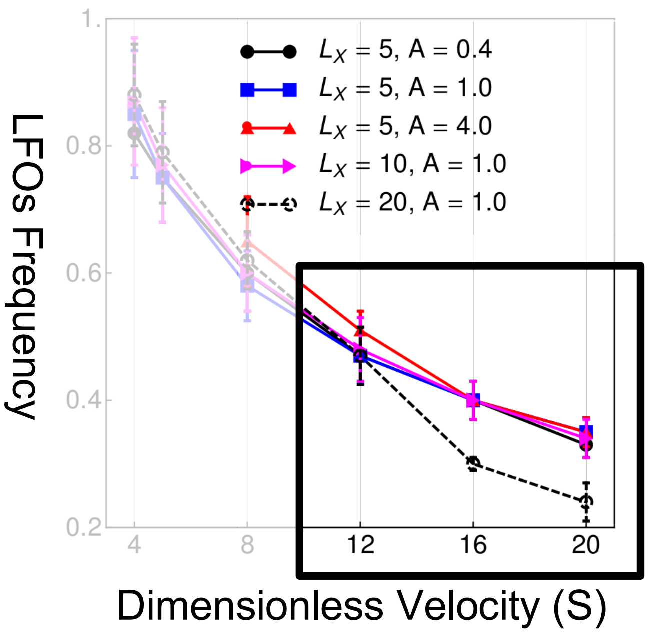
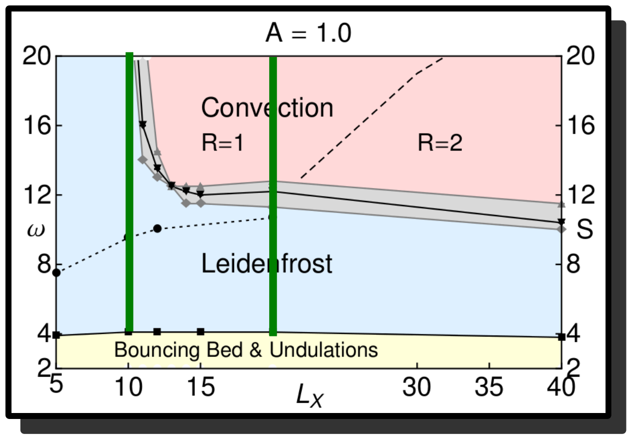


COLUMN: LFOs





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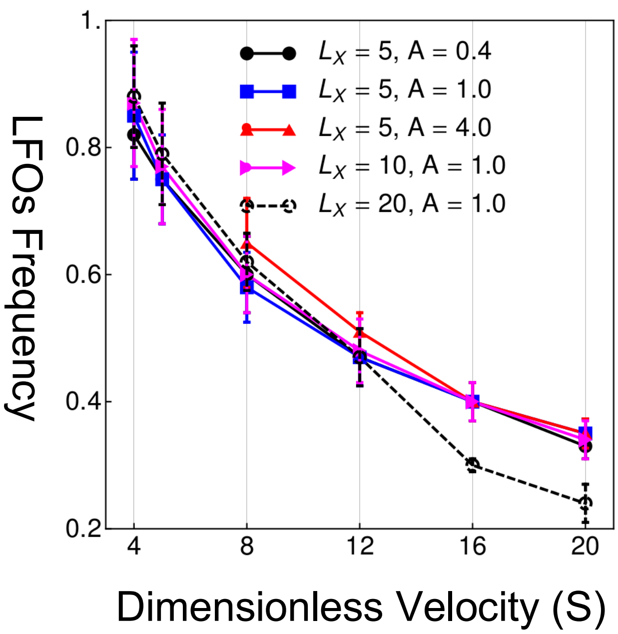
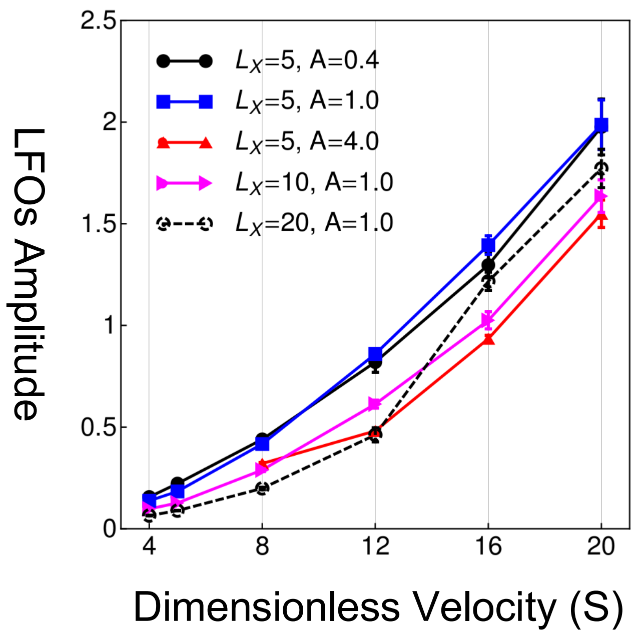
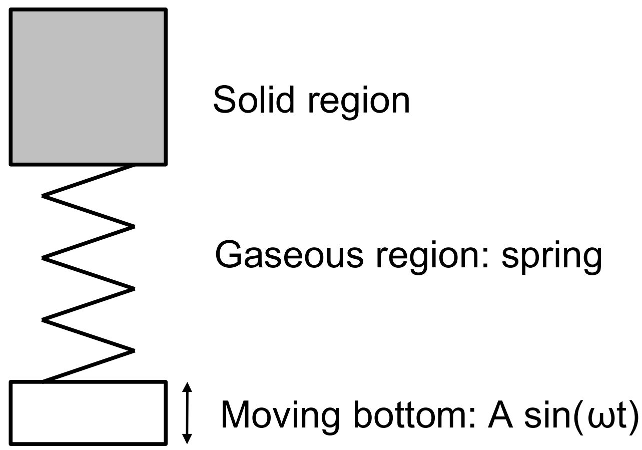




LFOs: MODEL



LFOs: MODEL

"Low-frequency oscillations in vertically vibrated granular beds"
N. Rivas, MSM, University of Twente

Mass conservation and Cauchy momentum equation:

$$\frac{D\rho}{Dt} + \rho(\nabla \cdot \vec{u}) = 0$$

$$\frac{D}{Dt}(\rho\vec{u}) = \nabla \cdot \tilde{\sigma} + \rho\vec{B}$$

ρ: Density
u: Velocity vector
σ: Stress tensor
B: External forces

LFOs: MODEL

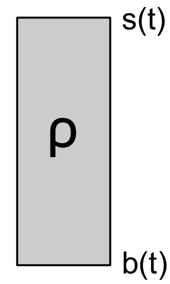
ρ: Density
u: Velocity vector
σ: Stress tensor
g: Gravity accel.

Considering a one-dimensional system,

$$\vec{u} = v(z,t),\ \rho = \rho(z,t),$$

one obtains a simple momentum equation:

$$\rho \partial_t v = \partial_z \sigma_{zz} - \rho g.$$

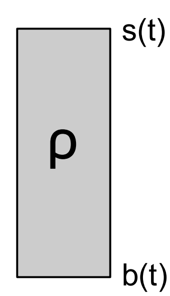


LFOs: MODEL

ρ: Density
u: Velocity vector
σ: Stress tensor
g: Gravity accel.

Integrating over the height:

$$\int_b^s \rho \partial_t v \mathrm{d}z = \int_b^s \partial_z \sigma_{zz} \mathrm{d}z - \int_b^s \rho g \mathrm{d}z$$



LFOs: MODEL

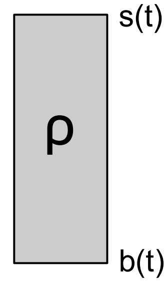
Integrating over the height:

$$\int_b^s \rho \partial_t v \mathrm{d}z = \boxed{\int_b^s \partial_z \sigma_{zz} \mathrm{d}z} - \int_b^s \rho g \mathrm{d}z$$

Stress boundary conditions:

$$(\tilde{\sigma} \cdot \hat{z})_{z=s} = 0.$$
$$(\tilde{\sigma} \cdot \hat{z})_{z=b} = \rho_g A^2 \omega^2 \cos(2\omega t)$$

ρ: Density
u: Velocity vector
σ: Stress tensor
g: Gravity accel.
A: Forcing amplitude
ω: Forcing frequency



LFOs: MODEL

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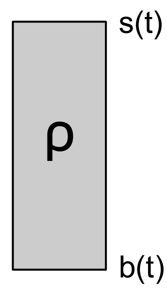
Using stress boundary conditions:

$$\int_b^s \rho \partial_t v \mathrm{d}z + \int_b^s \rho g \mathrm{d}z = \rho_g A^2 \omega^2 \cos(2\omega t)$$

ρ: Density
u: Velocity vector
σ: Stress tensor
g: Gravity accel.
A: Forcing amplitude
ω: Forcing frequency



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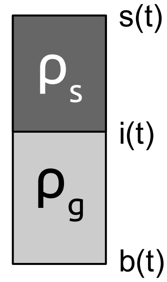


Using stress boundary conditions:

$$\int_b^s \rho \partial_t v \mathrm{d}z + \int_b^s \rho g \mathrm{d}z = \rho_g A^2 \omega^2 \cos(2\omega t)$$

We divide the system into two constant density regions:

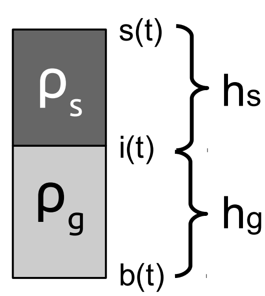
$$\rho_g \int_b^i \partial_t v \mathrm{d}z + \rho_s \int_i^s \partial_t v \mathrm{d}z + g \left(\int_b^i \rho_g \mathrm{d}z + \int_i^s \rho_s \mathrm{d}z \right)$$

To eliminate the z dependency, we depth average:

$$\bar{f} = \frac{1}{h} \int_b^s f \mathrm{d}z.$$

LFOs: MODEL

ρ: Density
u: Velocity vector
σ: Stress tensor
g: Gravity accel.



Then, depth averaging:

$$\rho_g \partial_t (h_g \bar{v}_g) + \rho_s \partial_t (h_s \bar{v}_s) + g\left(\rho_g h_g + \rho_s h_s\right)$$

Assuming $\partial_t h_s = 0$, and noticing that $\bar{v}_g = \bar{v}_s = \dot{i}$,
we get:

$$\rho_g \partial_t (i \dot{i}) + \rho_s h_s \ddot{i} + g \rho_g i + g \rho_s h_s = \rho_g A^2 \omega^2 \cos(2\omega t)$$

Disregarding non-lineal terms:

$$\ddot{i} + \frac{g \rho_g}{\rho_s h_s} i = \frac{\rho_g A^2 \omega^2}{\rho_s h_s} \cos(2\omega t) - g$$

LFOs: MODEL

Forced harmonic oscillator:

$$\boxed{\ddot{i} + \frac{g\rho_g}{\rho_s h_s} i = \frac{\rho_g A^2 \omega^2}{\rho_s h_s} \cos(2\omega t) - g}$$

Solution given by:

$$z(t) = A\sin(\omega_0 t) + B\cos(\omega_0 t) + \frac{F_0}{\omega_0^2 - \omega_f^2}\sin(\omega_f t)$$

With A and B given by initial conditions, and:

$$\omega_0^2 = g\rho_g/\rho_s h_s \qquad F_0 = \rho_g A^2 \omega^2/\rho_s h_s$$

ρ: Density
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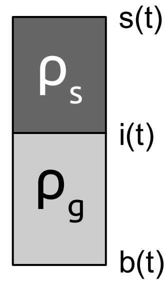

LFOs: MODEL

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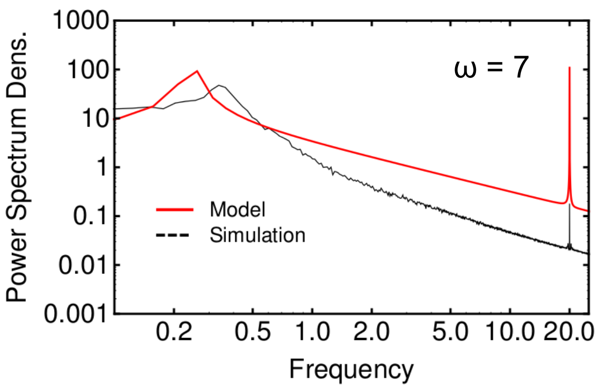
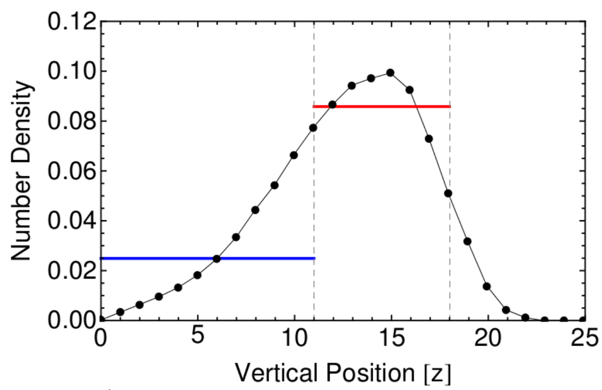




30% disagreement for ω = 10, 50% for ω = 5.

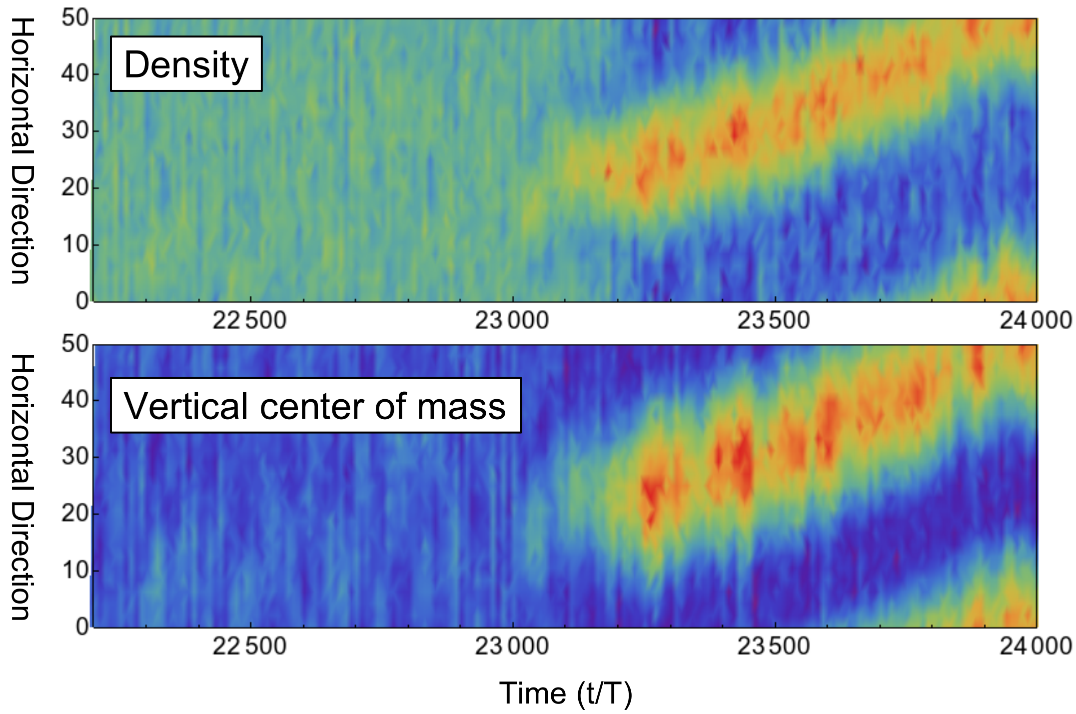
STATES

CONVECTIVE STATE

F = 12, ω = 10, A = 1.0

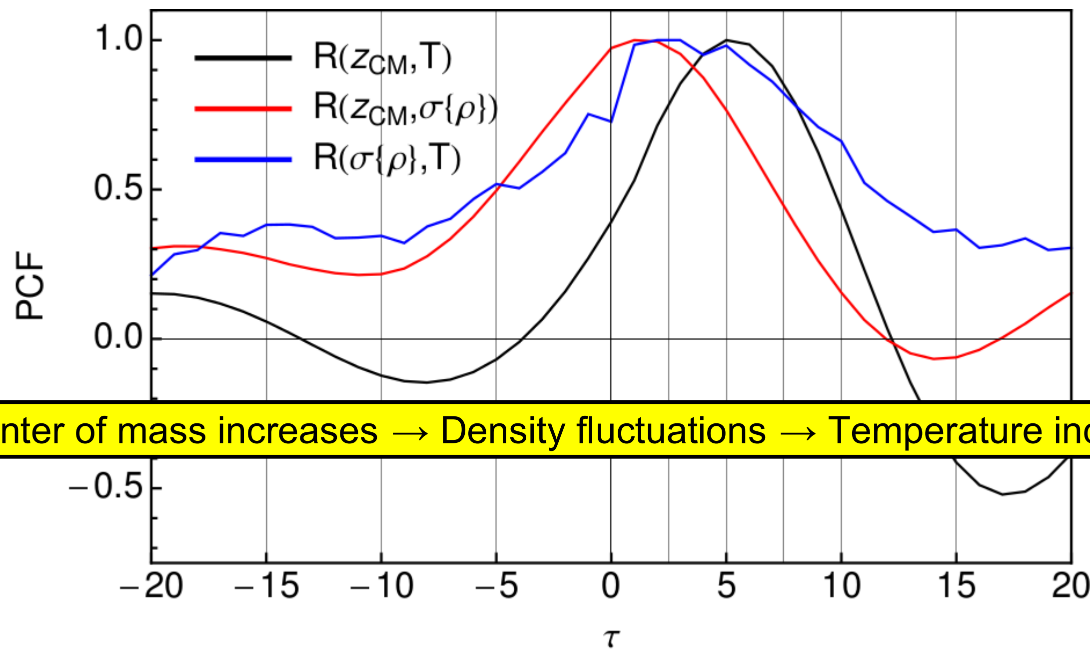
* Color corresponds to kinetic energy

LFOs: MODEL



LFOs IN TRANSITION

Fields time correlation:



Center of mass increases → Density fluctuations → Temperature increases

CONCLUSIONS

+ Vertically driven granular matter in density inverted states present low-frequency oscillations (LFOs).

+ LFOs are inherent to driven continuum systems in density inverted states.

+ LFOs may play a determinant role in the Leidenfrost to convection transition.

FUTURE

+ Expand the model:
  - Scaling should give limit of one-dimensional approximation.
  - Include non-lineal terms.
  - Consider a coupled oscillators system.

+ Study further the role of LFOs in wider systems.

+ Is it possible to observe LFOs in fluids?

+ Experiments!