Travail , Dissipation et second principe de thermodynamique dans les milieux granulaires

une retombée de la physique spatiale
incomprise ou .... une folie

Pierre Evesque

ECP-CNRS, « Lab MSS Mat, umr 85 79 (?) »

http://www.poudres-et-grains.ecp.fr/

Film: Site web: Palais de la Découverte : un chercheur une manip/**Poudres, grains et vibrations…sur terre et en apesanteur** **au Palais Du** 27 février au 27 avril 2008

Explications en 3 temps:

- Modèles / expériences et simulations
- Une interprétation basée sur l'Eq. De Boltzmann
- Et le second principe

Remarques:

Difficulté pour écrire et parler en congrès

Difficulté pour venir ici

Test psy /comité médical (je me crois en Russie) …. Peer review

3d simulations of granular gas in a vibrating box:

Demonstration of a large boundary effect due to dissipation by collisions which is not a propagating shock wave

P. Evesque, R. Liu, Y. Chen, M. Hou

R. Liu , MSSMat, ECP , France (Oct 2008-2009) , & IOP-CAS, China
M. Hou , " " & IOP-CAS, China
Y. Chen, P. Evesque, MSSMat, ECP , France & IOP 2009-2013

Thanks to ESA , CNES , CNSA

The flights: Satellite SJ8 ∫ VIP-Crit

2010: Essai de prédation (Pouliquen, Falcon, Vandewalle,…)

Why Studying
Granular Matter in Micro-gravity.

Experiments on vibrated granular matter in micro-gravity

Behaviour of granular dissipative gas under vibration

- to Study gas, cluster formation ?
- to Test the foundations of statistical Mechanics
- to Test the validity of the theoretical approach / approximations

More Importantly: to learn How to handle grains in 0-g to generate industrial processes…. & allow human life in space

Grains in 0g may be quite dangerous (breath - command)

Accurate comparisons lead to a series of puzzling questions for theorists of hydrodynamics and of disordered systems

Experimental study in 0g

Minitexus 5 (1998), Maxus 5 (2003) , Maxus 7 (2006), SJ8 (2006); A300-0g

► **Incompatibility of our experimental results in 0g compared to simulations**

- **n $_{layer}$ >1 : particle speed < wall speed => « supersonic excitation »**
- **but No Shock waves**
- **bad coupling when $V_{ball} << V_{wall}$ - boundary effect**

Is wall a thermostat or a velostat?? …

So we have shown that accurate study of experimental results lead to a series of puzzling questions that are not yet understood / described by theorists of hydrodynamics and of disordered systems nor by simulations.

However it requires to look in some details to what does not work

How to confirm, confort or test our results? with simulations? What to test ?

Explications en 3 temps:

1) Modèles / expériences et simulations

2) Une interprétation à base de l'Eq. De Boltzmann

3) Et le second principe

Remarques:

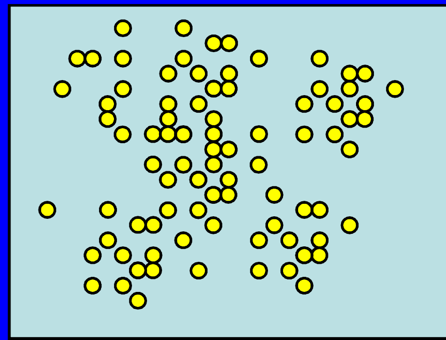
- **Difficulty to speak**
- **Difficulty to come**
- **Psychiatic evaluation/comité médical**

State of the art on simulations of Granular gaz and theoretical predictions

1995-2009…

Hypotheses

- No Rotation or rotation (no matter)
- Boundary conditions (no matter)
- Restitution coefficient



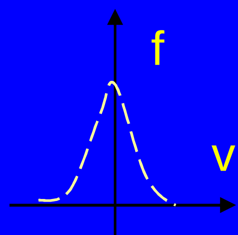
Inhomogeneous collapse and clustering

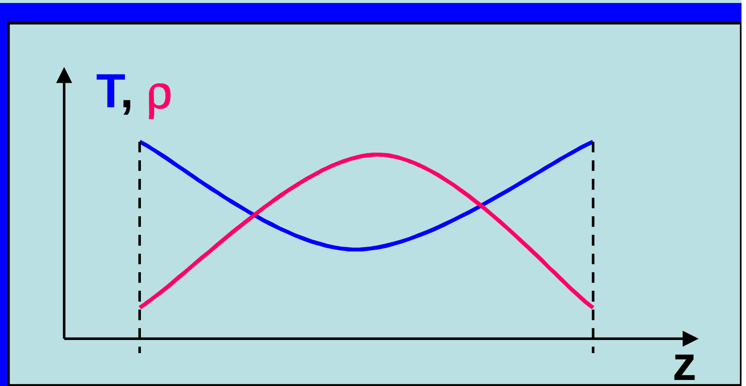
T_1, T_2, $\rho(z)$, $T(z)$, $f(v) \propto \exp[-(v^2/kT)^a]$

with a not far from 1

Conclusion : Right parameters

- Effective temperature
- constant Pressure
- Kinetic theory works with thermal balance for dissipation





Simulation results using DEM

+

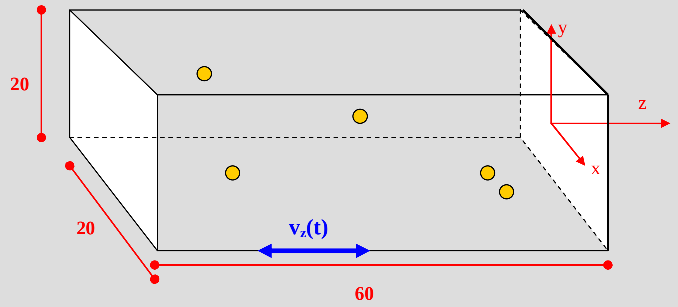
(not in R. Liu thesis, clustering and MD)

R. Liu stay in ECP during Thesis (Oct-2008-2009)

+

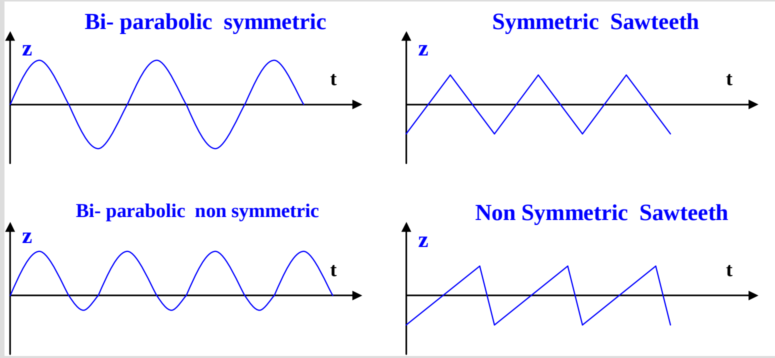
Y. Chen, Thesis: 2d Paraboloic flight,
2d exp in Horizontal plane
2d simulations
2d Inclined vibration (small effective g)
(2009-2013)

Simulations:



Cell: 20d*20d* 60d

Wall Motion kinds



+ Thermal wall

Parameters:

e = 0. 7 , 0. 8 and 0. 9

N = 100 , 500 , 1200, 1600, 2000, 3000, 4000, 4500

Measurements:

n(z)

PDF V_z at different z , PDF of V_x, at different z

$<V_z>$, ΣV_z= flow ; < V+>, <V->, F^+ et F^-

$p=\Sigma V^2_z$, $p^+ = \Sigma V^2{}_z{}^+$, $p^- = \Sigma mV^2{}_z{}^-$,

$T = \Sigma mV^2_z / \Sigma m$; $T^- = \Sigma mV^2{}_z{}^- / \Sigma m$; $T^+ = \Sigma mV^2{}_z{}^+ / \Sigma m$

Simulation N=1200; PDF V_z, V_x

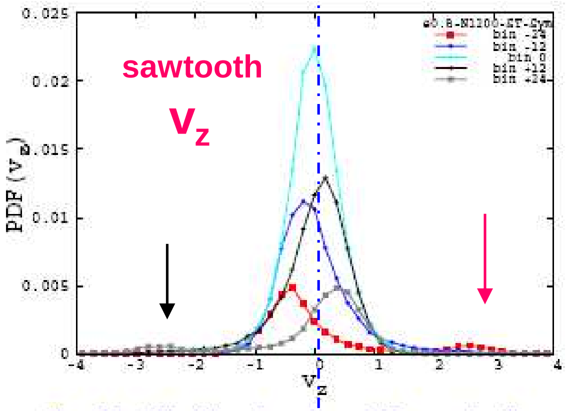
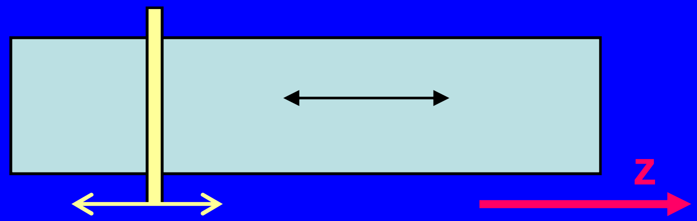


Figure 2.2 - 4: Simulations of granular gas is 3d rectangular cell



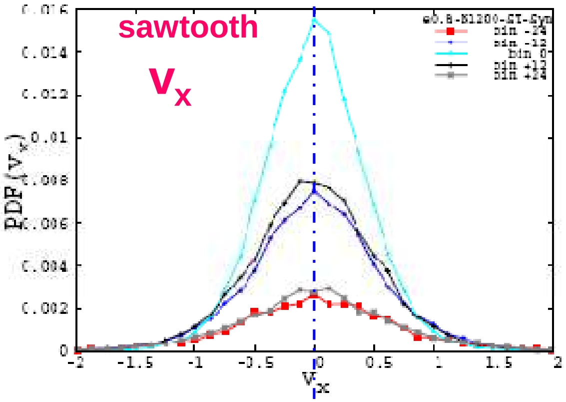


Figure 2.2 - 4: Simulations of granular gas is 3d rectangular cell

PDF V_z in log
shoulder is amplified at large z

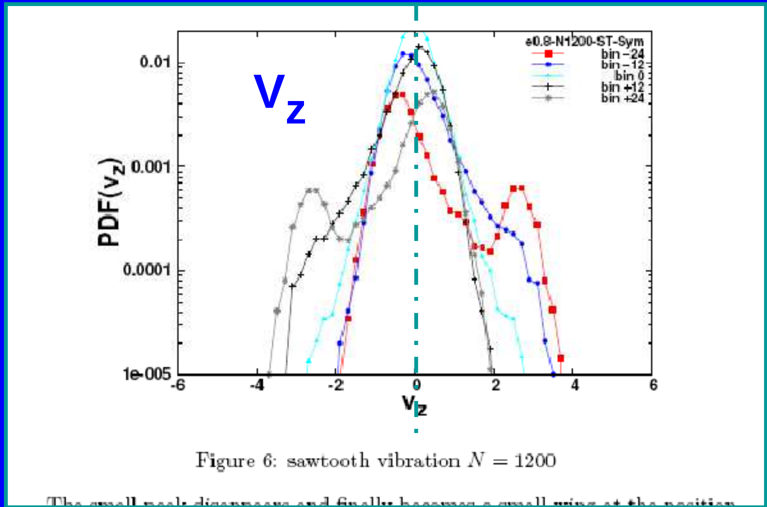
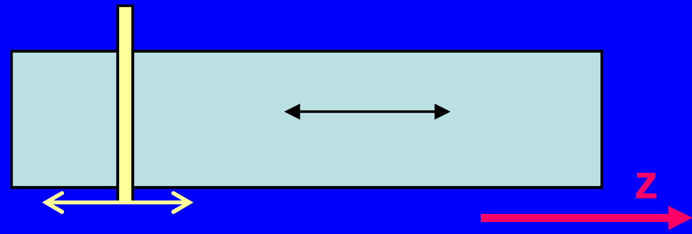


Figure 6: sawtooth vibration $N = 1200$



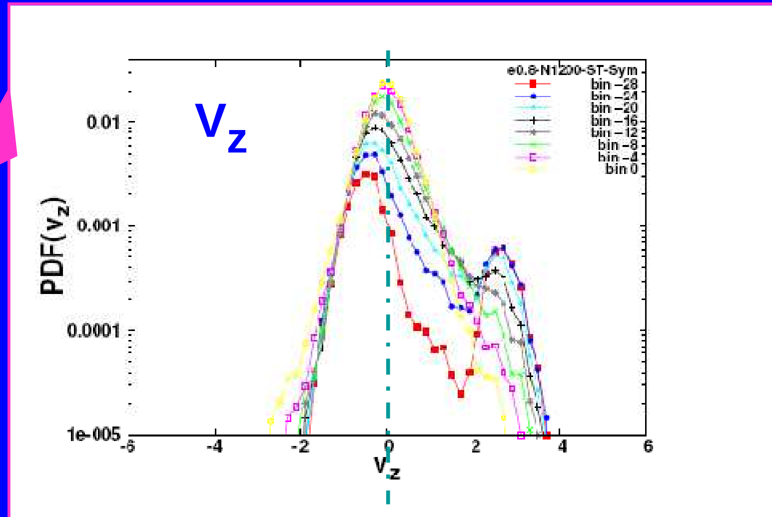


Figure 10: sawtooth vibration $N = 1200$

-The shoulder disappears at half the cell (bin ±12 over ±30)

- The maximum goes to left of z=0

Simulation N=1200; PDF V_z, V_x

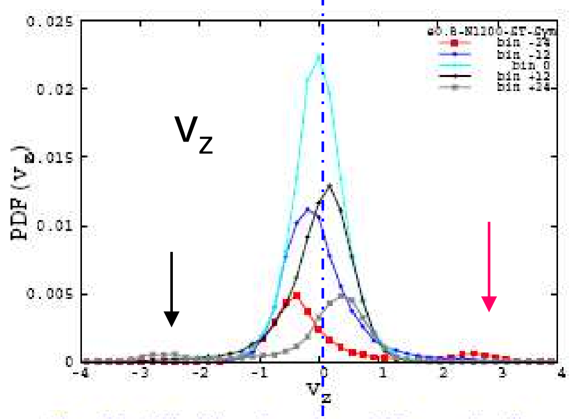
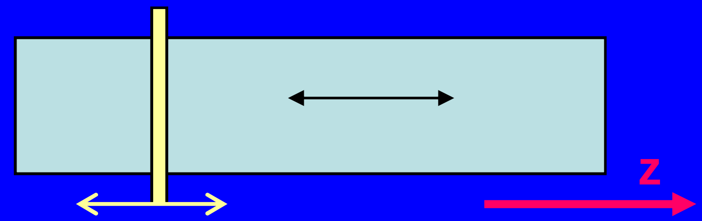


Figure 2.2 - 4: Simulations of granular gas is 3d rectangular cell



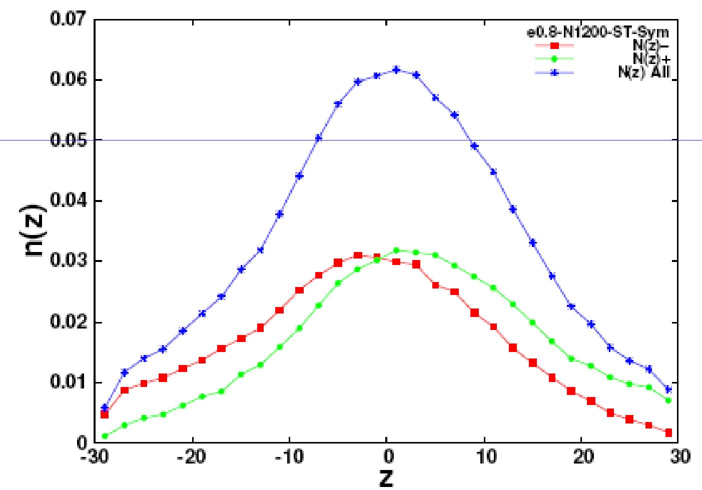


Figure 15: sawtooth vibration $N = 1200$

$V_z^+ \neq V_z^-$; steady state => $n^+V_z^+ + n^- V_z^- = 0$

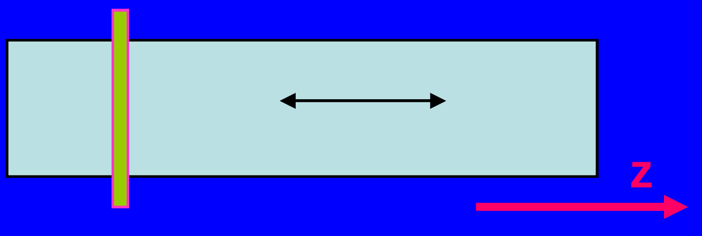
Difference between T^+ & T^-; P^+ & P^-

If $V_z^+ \neq V_z^-$ and steady state => $n^+v_z^+ + n^-v_z^- = 0$

$p_z^+ \neq p_z^-$ and $T^+ \neq T^-$

$$P_z^{\pm}(z) = \Sigma_v\, \rho(v_z^{\pm},z)\, V_z^{\pm\,2} = \mathrm{sum}_{at\ z}(V^{\pm}{}_z{}^2)$$

$$T^{\pm}(z) = \Sigma_v\, \rho(v_z^{\pm},z)\, V_z^{\pm\,2} \,/\, [\Sigma_v\, \rho(v_z^{\pm},z)] = \langle V^{\pm}{}_z{}^2 \rangle$$



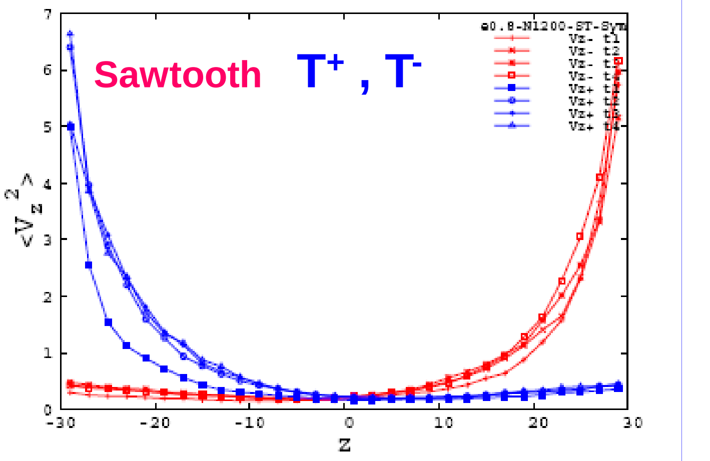


Figure 2.2 - 4: Simulations of granular gas is 3d rectangular cell

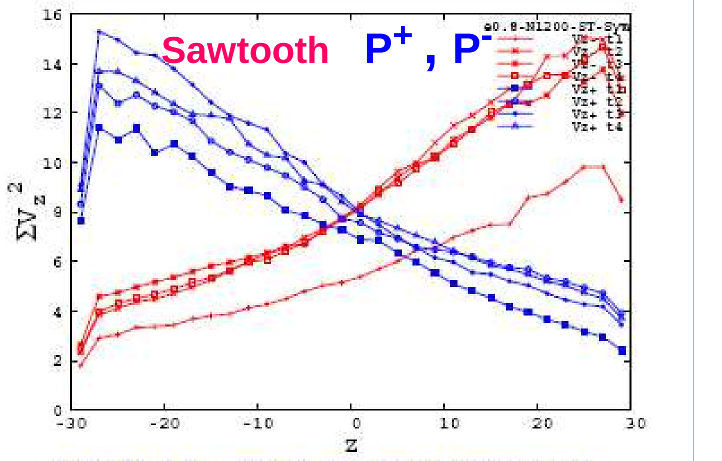


Figure 2.2 - 4: Simulations of granular gas is 3d rectangular cell

Comparison with Simulation from others:
averaging over whole cell

Most results • tell no difference with the kind of excitation (Sawtooth, sinus)
•• do not give local speed distribution, define only one T(r) (at best).
••• look at averaged f(v) as $f(v) \approx \exp-[(\beta v^2/T)^{\alpha}]$

=>equivalent to mean field treatment / approximation (1995-2006)

Best finding:
2d case (W. Morgado & Eduardo R. Mucciolo Sawtooth exc. (2002) (= 2008)

5.1 the pressure.

J. J. Brey et al [arXiv:0906.0747] find some stationary sta pressure, like that in classical gases. But they also observe win distribution. Their system is quite near elasticity (e = 0.9 strongly dissipative system, whether the constant pressure ca undiscussed. And it is difficult to calculate the pressure in t the local mean free path is too short. $\sum v_z^2$ does not give any i the pressure if too many collisions there.

5.2 the stability of the cluster.

E. Khain and B. Meerson [Europhys. Lett., 65 (2), pp. discussed an oscillating phenomenon of the cluster in the center These results indicate that steady state sometimes is difficult number of particles N.

Three states of the cluster, i.e. a static cluster(singular), steady cluster, and an oscillating cluster, may be found.

5.3 wings and double-peak structures in velocity distribution.

Morgado and Mucciolo [Physica A 311 (2002) 150-168] disc and velocity distributions in a 2D system with their DSMC re founded in the longitudinal velocity distributions.

J. F. Boudet et al [PRL 101, 254503 (2008)] observed a sir structure near the shock front of an obstacle, which indicates two kinds of particles, in a granular flow.

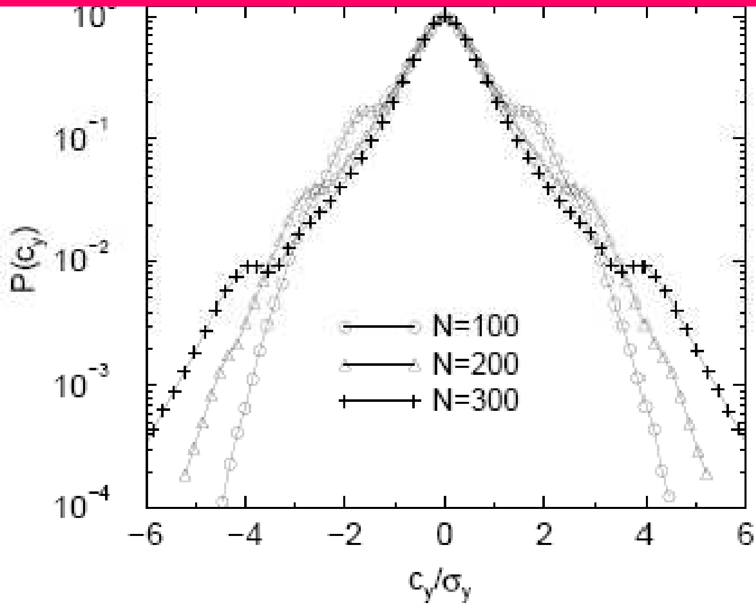


FIG. 3. The vertical (longitudinal) velocity distributions for the

Difference between sawtooth and sinus

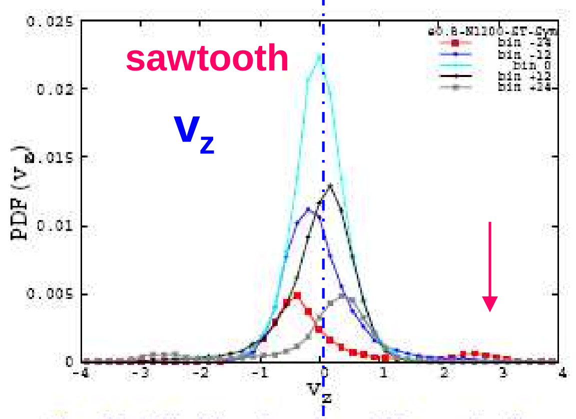


Figure 2.2 - 4: Simulations of granular gas is 3d rectangular cell

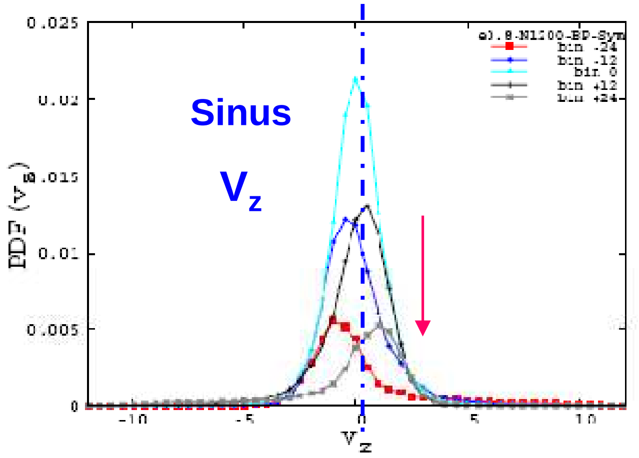
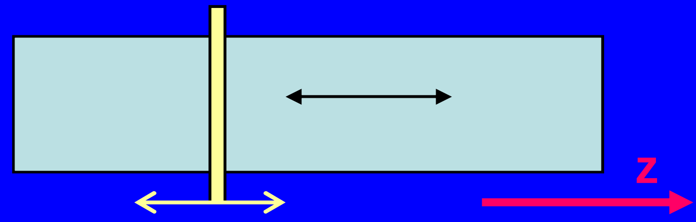


Figure 2.2 - 4: Simulations of granular gas is 3d rectangular cell



But still : $n^+ \neq n^-$; $P^+ \neq P^-$; $T^+ \neq T^-$

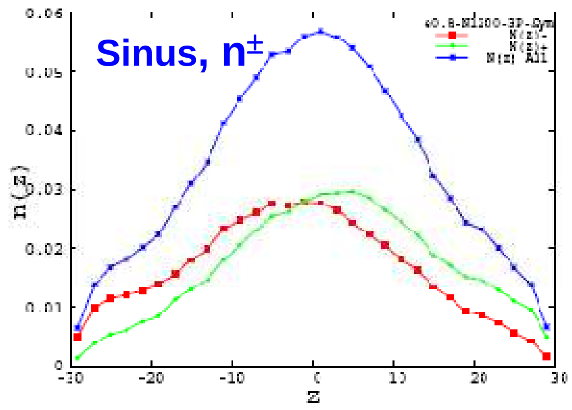


Figure 2.2 - 4: Simulations of granular gas is 3d rectangular cell

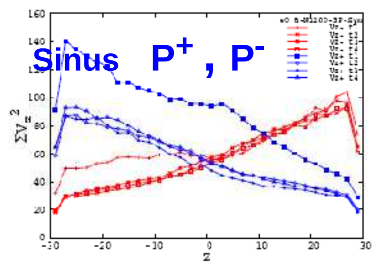


Figure 2.2 - 4: Simulations of granular gas is 3d rectangular cell

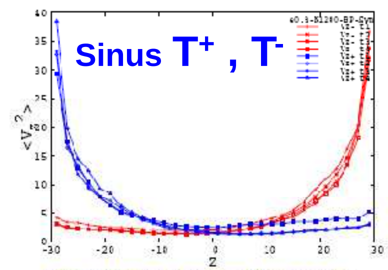


Figure 2.2 - 4: Simulations of granular gas is 3d rectangular cell

Difference of PDF V_z between sawtooth ,sinus, thermal wall (In log scale)

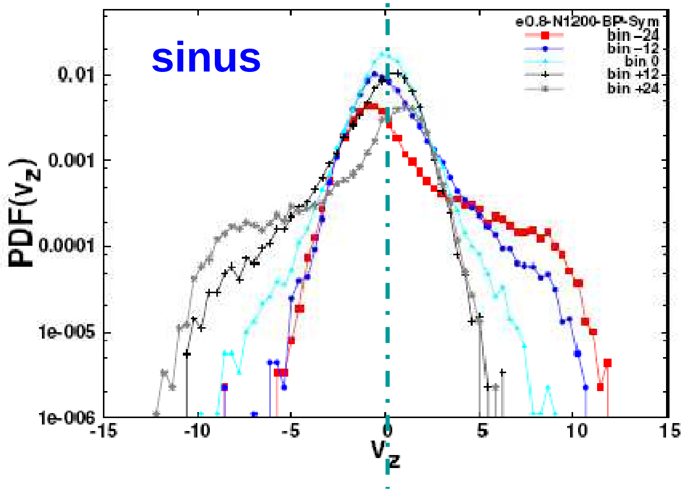
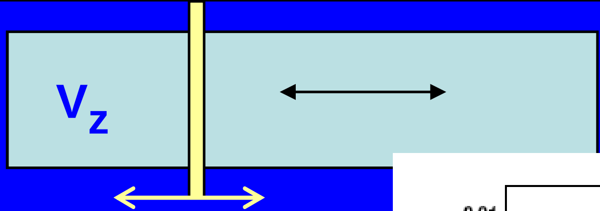


Figure 4: bi-parabolic vibration $N = 1200$



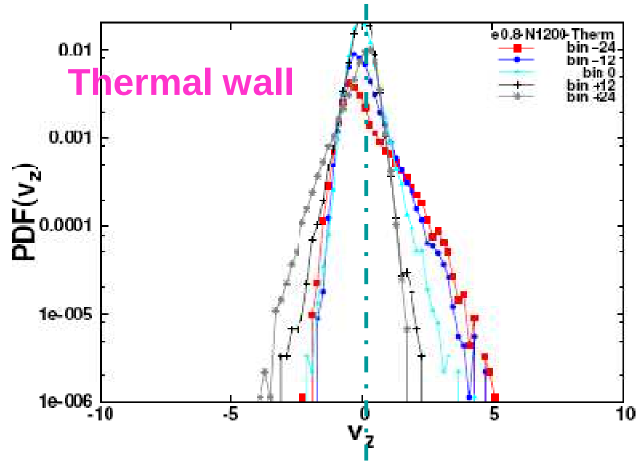
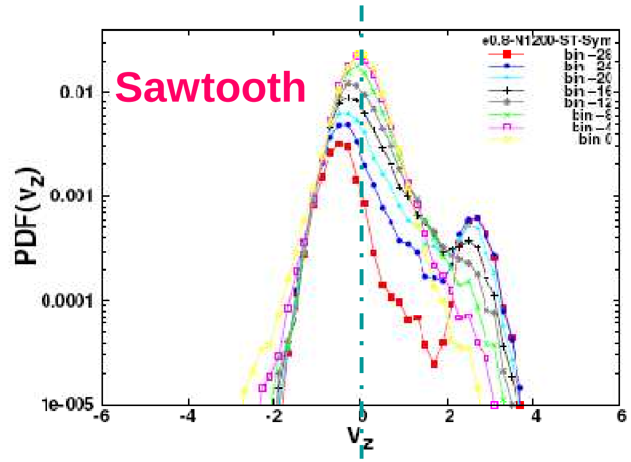


Figure 5: thermal wall $N = 1200$



PDF V_z is non symmetric

+ depends on z

It has 2 peaks only for sawtooth

Part 1: Conclusion 1 :

- **GG** is an interesting problem with a lot of **contradictions/unknown**
- Its statistics does not obey the one of a gaz with a single temperature:

  2 temperatures and **2 pressures** everywhere, in vibration direction

- This is linked to **boundary** conditions
- **This is observed** in **simulations** and in **experiments**

  and this despite the numerous publications **which deny/do not cite** this point

  or/but which have not checked this

- **0g and 1g experiments are not equivalent**

- **MD is not well understood, despite what tell the publications**

These are opened questions => SJ-10

We are still far from understanding the **structure of the universe**, **with stars, galaxies, …,dust**

We do not want to die with peas (or flour, coffee) , preparing some food… (in space)

We are facing also some problem about edition, and research management

Part 1: Conclusion 2:

Complex non linear systems need large amount of data to determine (non
- mean field) analysis

And correct analysis

Number of curves studied: **6 000** (3e *8N* 5 boundaries* 4t *12 plots(v, v²,..)

Poudres & Grains 17 (2009) (550 pages)

Generalisation

- This may happen very often for any flow with local jump and/or hydrodynamic discontinuities.
- i.e. Leidenfrost effect

This work uses concepts from my previous works:

- boundary = thermostat or velostat
- Problem of diffusive or/propagative Boltzmann equation
- True effect of fast boundary

physical idea: $V_+ \neq V_-$

Interpretation / Conclusion 3:

Impact with moving boundary => $V_+ >> V_-$ on –L & $V_+ << V_-$ at +L

Steady state => $\Sigma \rho_+ v_+ = \Sigma \rho_- v_-$ => $\rho_+ / \rho_- = v_- / v_+$

This makes the **speed-symmetry breaking** at ±L, that **propagates** with **decrease** to 0 at z=0

Characteristics:

- **2 different temperatures $T_\pm$ in any given position (z) for V_{+z} and V_{-z}.**
  since $kT_\pm / m = \langle \rho_\pm V_\pm{}^2 \rangle / \langle \rho_\pm \rangle \propto |V_\pm{}^2|$
- **2 different pressures $P_\pm$ in any given (z) since $P_\pm = \langle \rho_\pm V_\pm{}^2 \rangle \propto |V_\pm|$**

►This seems to be coherent with what we observed experimentally and not coherent/described in other simulations and theoretical descriptions (P=cst)

Nobody tested the non random distribution in GG

I hoped this wuld allow discussion but not

Explications en 3 temps:

1) Modèles / expériences et simulations

2) Une interprétation à base de l'Eq. De Boltzmann

3) Et le second principe

Remarques:

Difficulty to speak
Difficulty to come
Psychiatic evaluation/comité médical

BOLTZMANN EQUATION

$\partial\rho/\partial t + v\, \partial\rho/\partial x - g\, \partial\rho/\partial v = - \int du\, du'\, du'\, |u-v|\, \rho(v,x,t)\, \rho(u,x,t)\, d\{u'-v+\varepsilon(v-u)\}\, d\{v'-u+\varepsilon(u-v)\}$

$+ \int du\, du'\, dv'\, |v'-u'|\, \rho(u',x,t)\, \rho(v',x,t)\, d\{v-v'+\varepsilon(v'-u')\}\, d\{u-u'+\varepsilon(u'-v')\}$

+ 2nd order term (thermal and particle diffusion)

$$\partial\rho/\partial t + v\, \partial r/\partial x - g\, \partial\rho/\partial v = \varepsilon\, \partial\{ \int du\, (v-u)\, |v-u|\, \rho(v,x,t)\, \rho(u,x,t) \} /\partial v \quad (2)$$

With $\varepsilon=(1-e)/2$ is the dissipation coefficient linked to restitution coefficient e

The right hand part is non zero if the distribution is non symmetric.

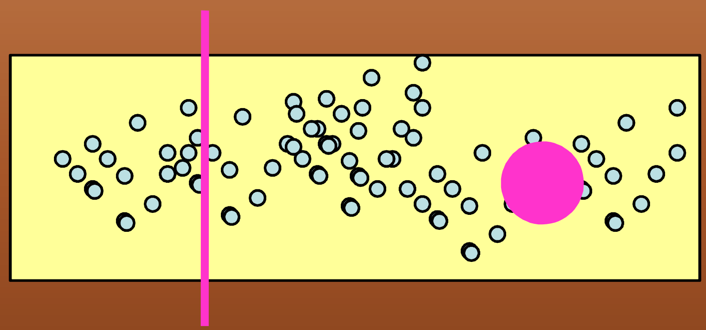
LAGRANGIAN POINT OF VIEW OF THE MECHANICS AND CAUCHY'S STRESS TENSOR

- **Material frame,** with point -volume like δm, δv
- ⇨ σ^+ & σ^- : $T^+ ds$ & $T^- ds$

=> $\rho g\, ds = (T^+ - T^-)\, ds$

- => pressure $p^+ = p^-$

$$\mathbf{p^+ = m\, \Sigma_{v>0} v^2 \neq p^- = m\, \Sigma_{v<0} v^2}$$



⇨ **The real wall moves toward the center**
The real big ball moves toward the center

EULERIAN POINT OF VIEW

One starts from the continuity equation

- ∂ρ/∂t + ρ div(**v) + v grad(r) = ∂ρ/∂t + div(**ρ**v)=0**

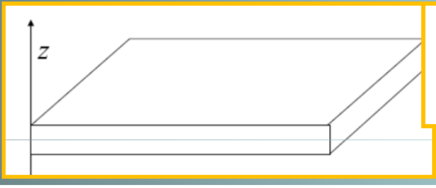
- And one defines the pressure…. P so $p^{+}=p^{-}$

Shaken sand , stress and test

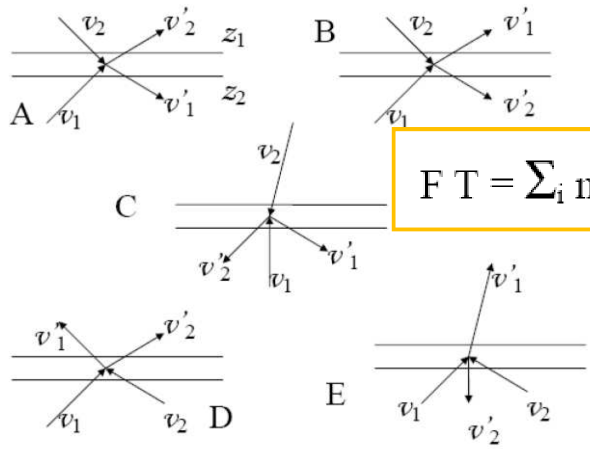
(J. Villain 2012)

- Limit of 2-body collisions

1) $P = P^+ + P^- = c^{onstante}$

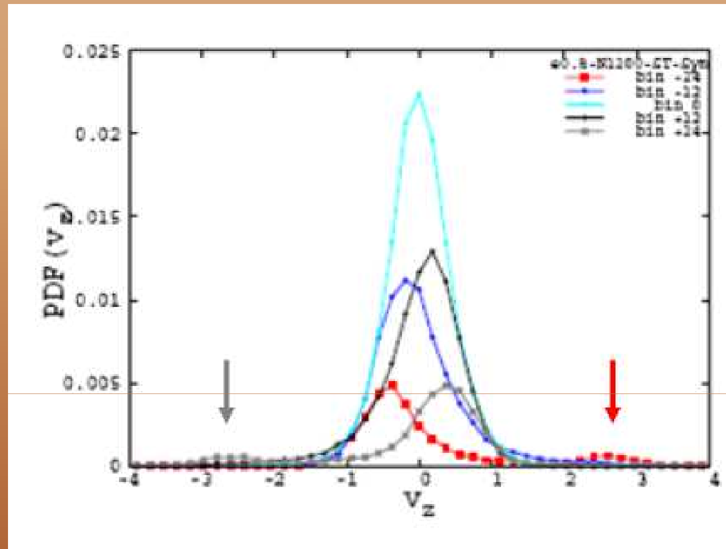


$$\int_0^T F_i(t)\, dt = m_i\, [v_i - v'_i]$$



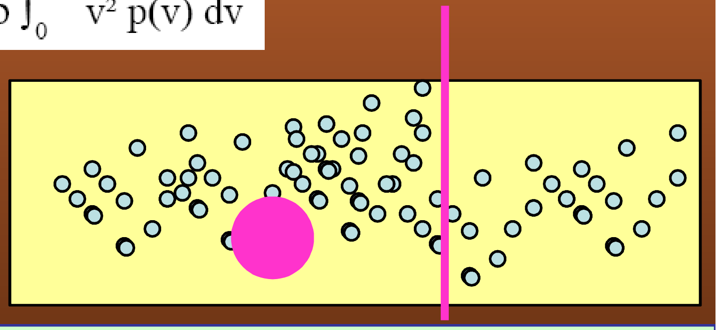
$$F\,T = \Sigma_i\, m_i\, v_i - \Sigma_r\, m_r\, v_r$$

Figure 3: Various types of collisions. The z-component of the velocities are denoted v_1 and v_2 (incoming particles), v'_1 and v'_2 (outgoing particles).



$$P^- = \rho \int_{-\infty}^{0} v^2\, p(v)\, dv$$

$$P^+ = \rho \int_{0}^{+\infty} v^2\, p(v)\, dv$$



1d Modeling

(Du, Li, Kadanoff 1995)

The Paper says:

- With few balls (2-20) they found hydrodynamics modelling is impossible
- This comes from dissipation
- And modified the equation

Explications en 3 temps:

1) Modèles / expériences et simulations

2) Une interprétation à base de l'Eq. De Boltzmann

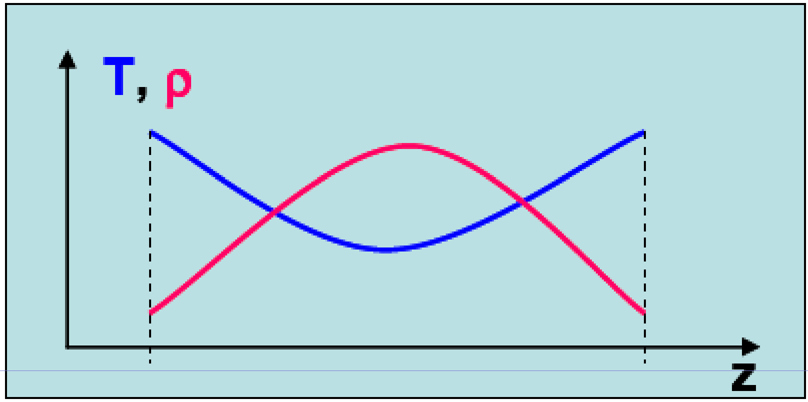
3) **Et le second principe** **de thermo**

Remarques:

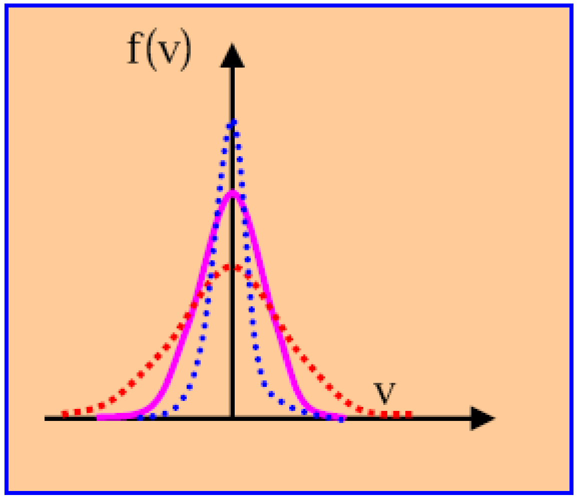
Difficulty to speak
Difficulty to come
Psychiatic evaluation/comité médical

Quelques examples

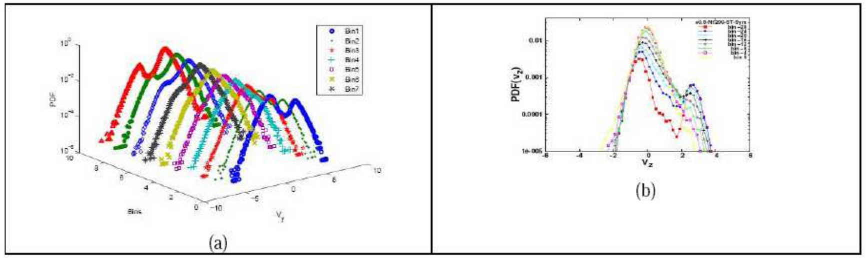
« Classic » view

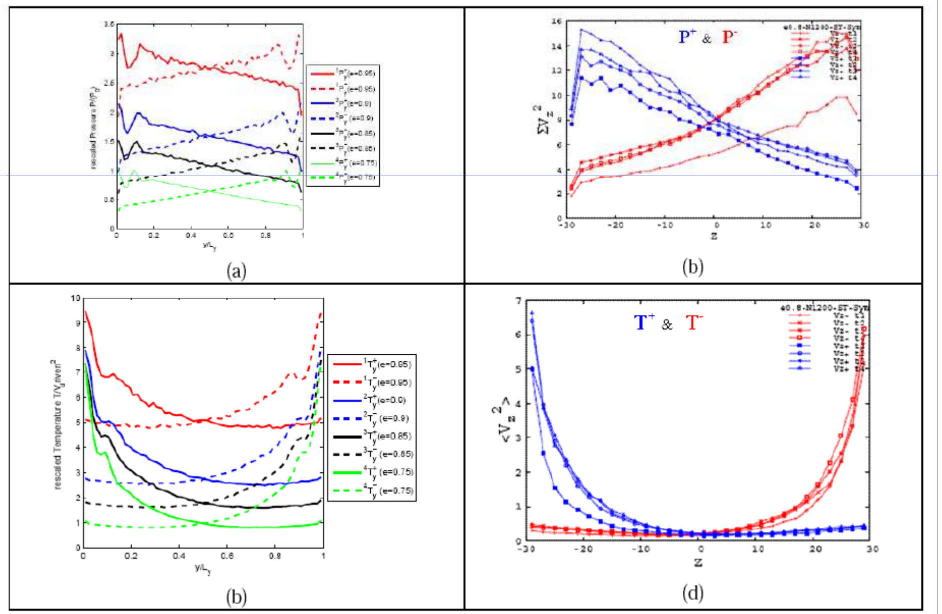


$$f(V,T)= A\,[n_T / (T^{d/2})]\, \exp(-V^2/(BT))$$



Real view

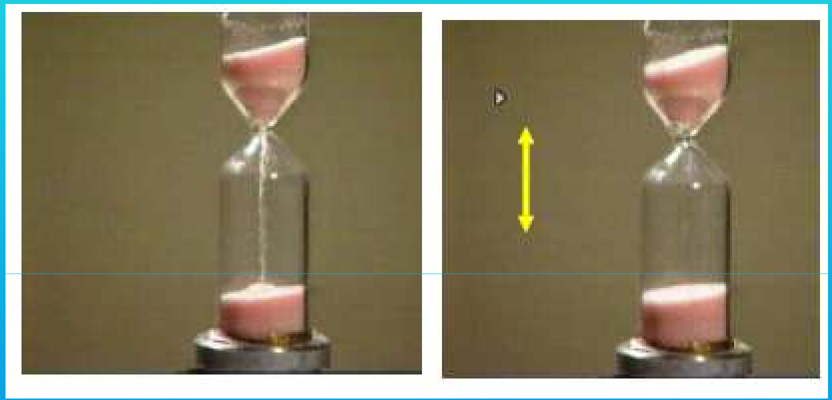


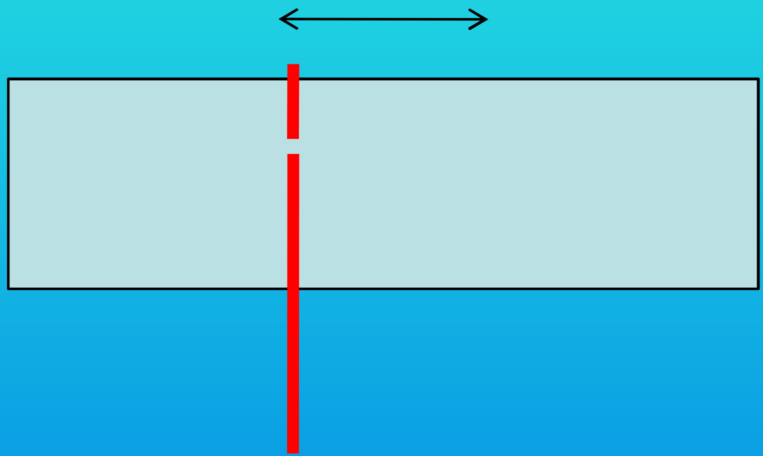


Woks for 2d & 3d simulations , Airbus 0g 2d results & 2d horizontal in 1g , + compatible with rochets and satellite exp.

Few new understanding

2nd principle : no work without 2 T





Leidenfrost effect or boiling crisis
Levitating hourglass
Clustering

Paroi => force centrale