Granular gases:

a window into (simple?) far from equilibrium systems

- Background and motivation
  - very (deceptively) simple non-equilibrium system
  - testing ground: kin. theory, simulation & expt.
  - *model* system
  - non-*Maxwell-Boltzmann* velocity distributions
- Questions (for us)
  - how to inject energy (boundary/uniform)?
  - role of spatial correlations?
  - how distinct, what controls behavior?

Jeroen van Zon,
Refs: *PRL*, **93**:038001 (2004); cond-mat/0205512.

Experiments Velocity correlations

Non-Gaussian (Boltzmann)

$P(v) \approx \exp\left(-Av^{\beta}\right)$, where $\beta \cong 1.55$

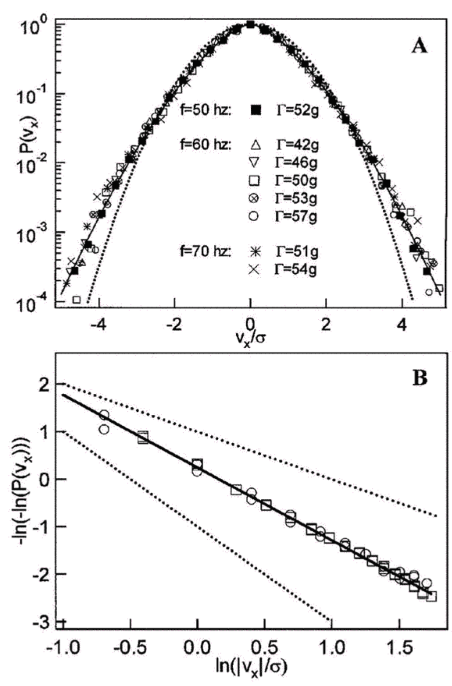
not

$$P(v) \approx e^{-mv^2/2kT}$$

Rouyer & Menon ‘01

See also

Olafsen & Urbach ’98, ‘99
Losert *et al*. ’99 (also $\beta \cong 1.5$)
Kudrolli *et al*. ‘97,’00, ’01
(not universal?)



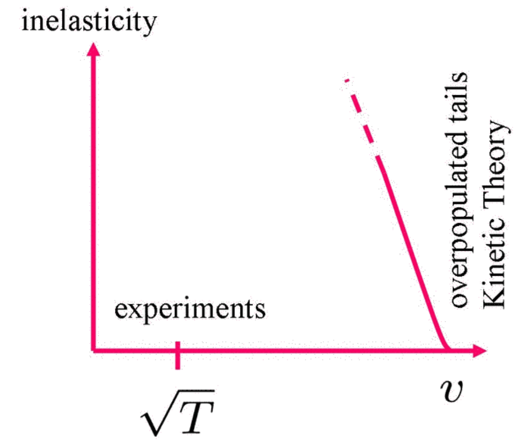
Approaches

Kinetic theories

e.g., van Noije & Ernst '98

Simulations

e.g., Moon *et al.* '01
Barrat & Trizac '02
Brey & Ruiz-Montero '03



Questions:

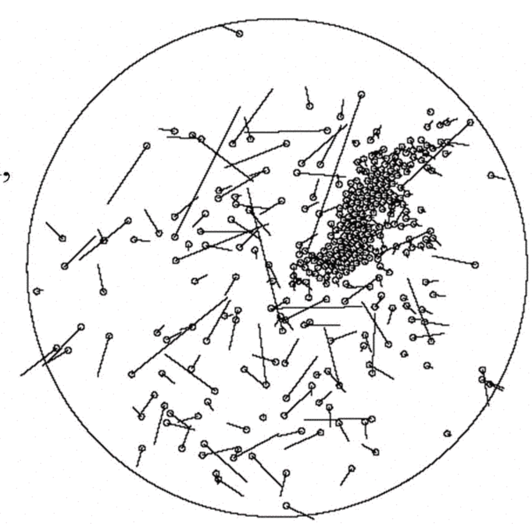
role/method of energy input?
role of spatial correlations?
why β<2, what controls this?

The model

event-driven simulation,

$$\mathbf{v}_i' = \mathbf{v}_i - \frac{1+\eta}{2}(\mathbf{v}_i \cdot \hat{\mathbf{r}}_{ij} - \mathbf{v}_j \cdot \hat{\mathbf{r}}_{ij})\hat{\mathbf{r}}_{ij},$$

η **<1**,
Coefficient
of restitution



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Velocity Distributions in Dissipative Granular Gases

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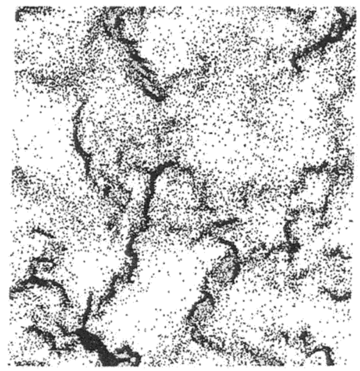
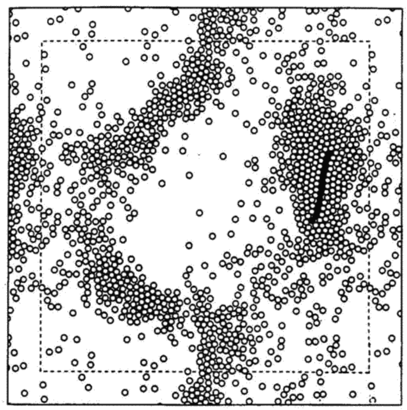
Clustering vs. Collapse

Inelastic collisions lead to clustering

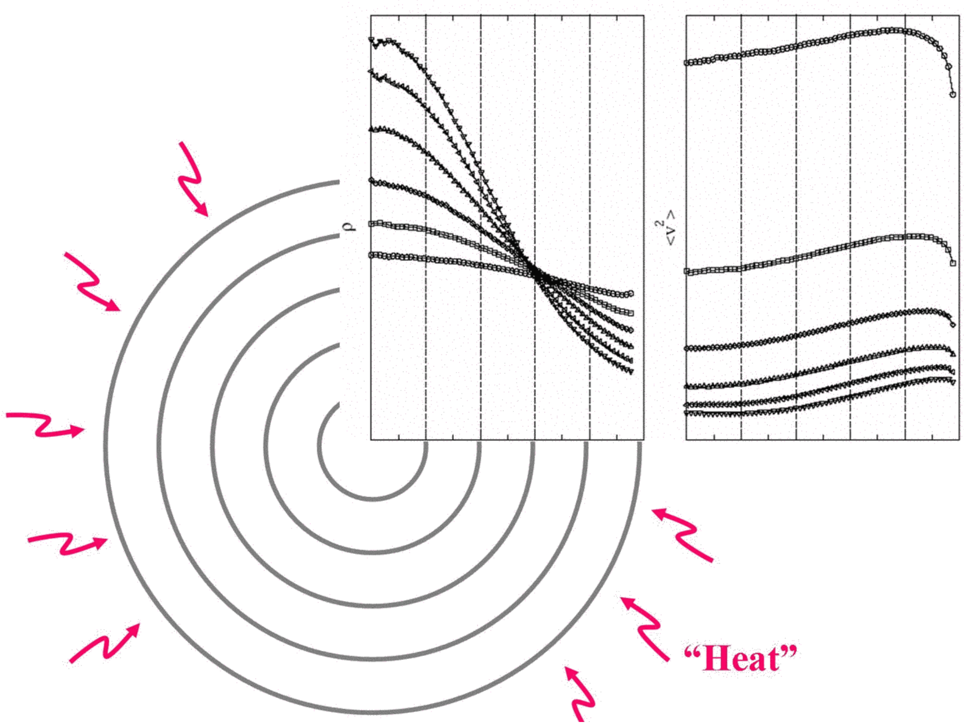


Goldhirsch & Zanetti, 1993

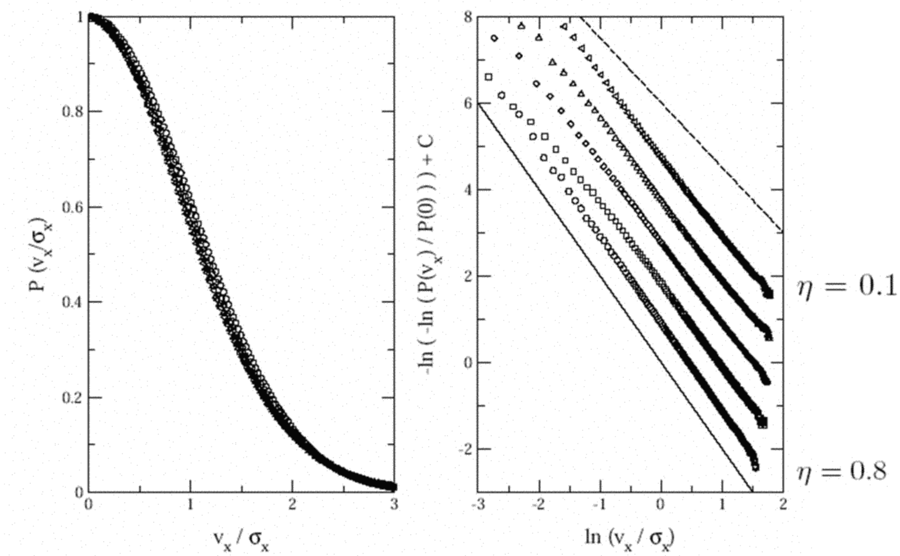


Collapse = *infinite* number of collisions in a *finite* time
(McNamara & Young, 1994)

Radial dependence

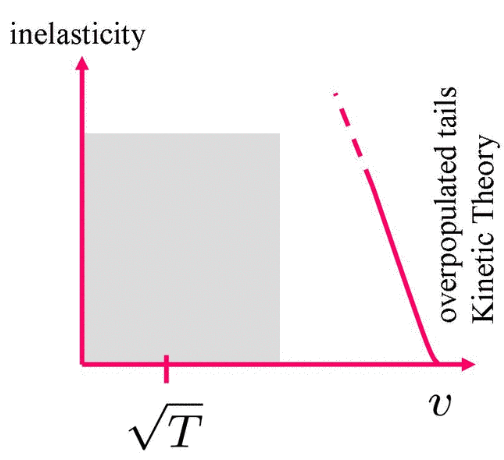


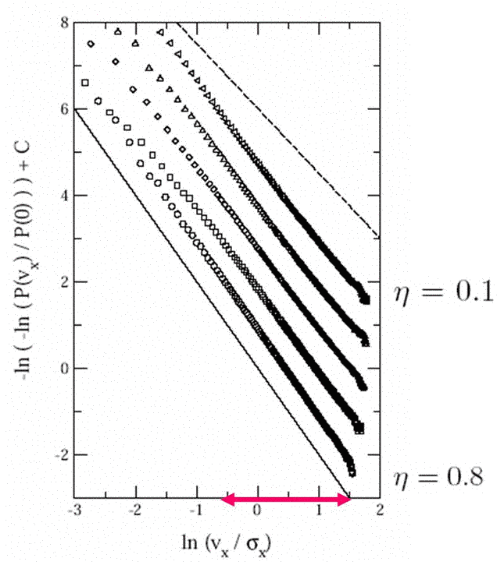
Uniform heating



Little significant deviation from Gaussian
- see also Barrat and Trizac, 2003
- Barrat, Trizac, & Ernst *cond-mat/0411435*

Uniform heating





Little significant deviation from Gaussian
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Boundary heating

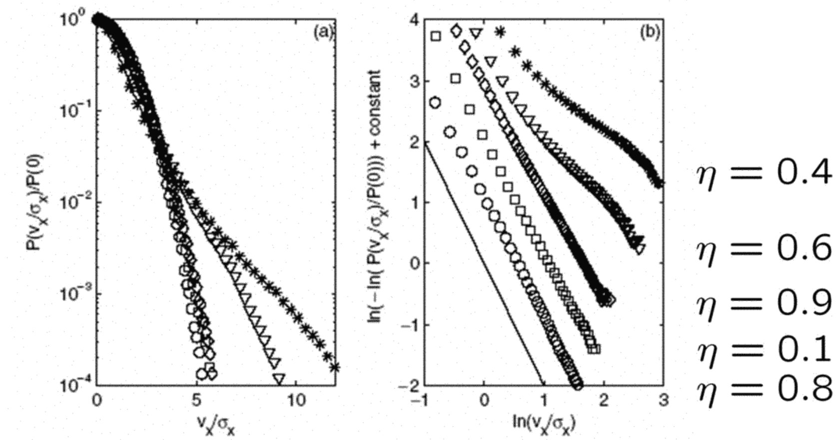


FIG. 2. Velocity distributions for $N = 350$ and $\phi = 0.02$. Shown are both results for uniform heating with $\eta = 0.8$ (○), $\eta = 0.1$ (□) and results for boundary heating with $\eta = 0.9$ (◇), $\eta = 0.6$ (▽), and $\eta = 0.4$ ($*$). (a) $P(v_x/\sigma_x)$; (b) $-\ln\{-\ln[P(v_x/\sigma_x)]\}$ versus $\ln(v_x/\sigma_x)$. A Gaussian is shown as a solid line.

Comparison with experiments

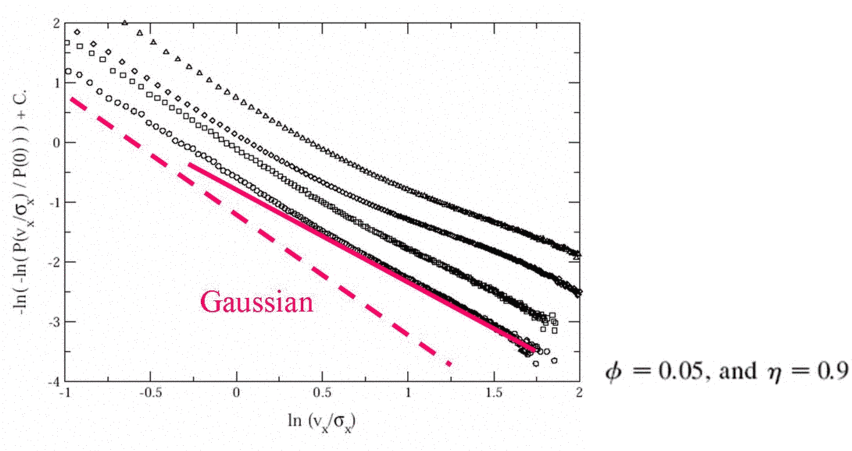
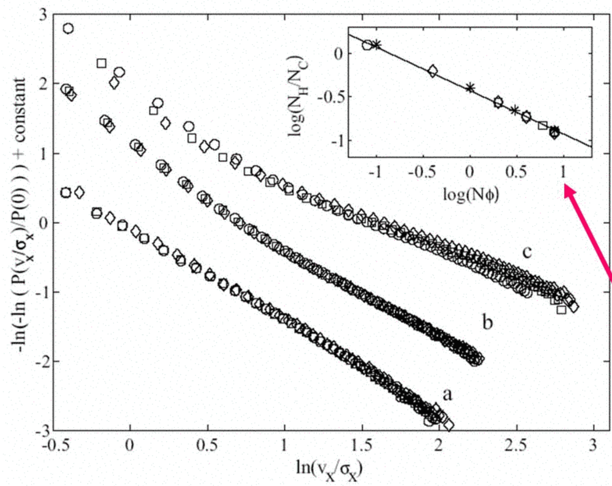


FIG. 10: Boundary heating. (a) $-\ln\{-\ln[P(v_x/\sigma_x)]\}$ versus $\ln(v_x/\sigma_x)$ for $N = 350$, $\phi = 0.05$ and $\eta = 0.9$ (○), $N = 500$, $\phi = 0.05$ and $\eta = 0.9$ (□), $N = 350$, $\phi = 0.05$ and $\eta = 0.8$ (◇), $N = 350$, $\phi = 0.25$ and $\eta = 0.9$ (△). The solid lines correspond to the fit as made by Rouyer and Menon and has an exponent $\alpha = 1.52$. The range of the solid lines corresponds to half the range used by Rouyer and Menon in their fit, but contains about 80% of their data points

What controls non-Gaussians?



Data collapse for various ϕ, N, & η

$$q = \frac{N_H}{N_C}$$ heating / collisions

Estimates:

$$\ell_c \sim 1/\phi$$

$$\ell_h \sim (N/\phi)^{1/2}$$

$$q \sim 1/(N\phi)^{1/2}$$

Spatial correlations irrelevant

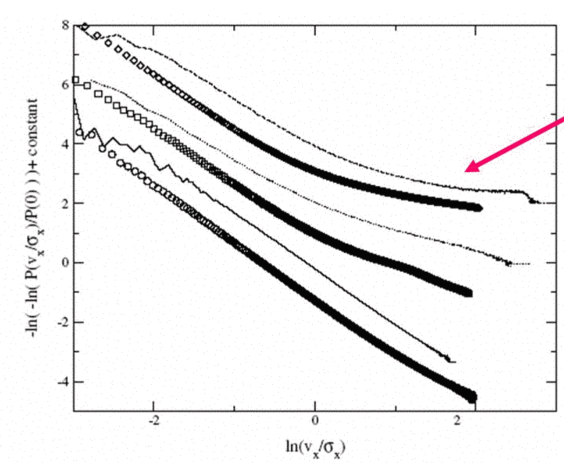


FIG. 5. $-\ln\{-\ln[P(v_x/\sigma_x)]\}$ versus $\ln(v_x/\sigma_x)$. The symbols shown are velocity distributions acquired by simulation for $q =$ 120 (uniform heating, ○), 0.08 (boundary heating, □), 0.012 (homogeneous two-point heating [4,13], ◇). The lines show the velocity distributions found in the model for the same values of q (solid, dotted, dashed, respectively).

no spatial degrees of freedom, but same q

Granular gases:

a window into (simple?) far from equilibrium systems

- non-Gaussian distributions
  - NOT "overpopulated" tails of kinetic theory
  - continuous range of effective exponents
- Boundary vs. uniform/homogeneous heating
- Importance of energy *cascade*
  - energy input at rate N_H
  - dissipated at rate N_C
  - important parameter $q = N_H / N_C$
- Role of spatial correlations