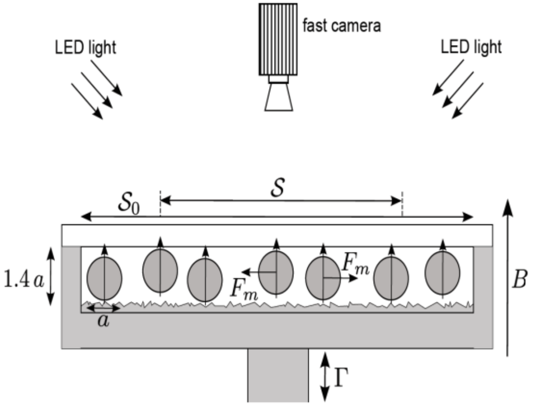
“Granular turbulence” in a driven system of magnetized particles

Michael Berhanu[1], Simon Merminod[2], Gustavo Castillo[3] & Eric Falcon[1]

[1] MSC, Université de Paris, France, [2] Harvard University, MA, USA, [3] Universidad O'Higgins, Rancagua, Chile



2000 soft iron particles vibrated and immersed in a vertical magnetic field B.
Quasi 2D cell 90 x 90 mm
See Merminod, Berhanu & Falcon EPL 2014
Meminod PhD 2016

Kinetic energy per particle

$$E_c = \frac{1}{2} m \left\langle v_x^2 + v_y^2 \right\rangle$$

Potential energy per particle

$$E_m = \frac{1}{N} \sum_{i=1}^{N} \sum_{j=i+1}^{N} U_{m,ij}$$

$$\varepsilon = \frac{E_m}{E_c} \propto \frac{B^2}{\langle ||\mathbf{v}_{\mathrm{rms}}||^2 \rangle}$$

Acceleration rms Γ=1.6 g
0 < B < 430 G

2D velocities
from particle tracking

$U_{m,\langle ij\rangle}$ dipolar potential energy of a pair ij

$$U_{m,\langle ij\rangle} = -\frac{\pi}{16\mu_0} B^2 \frac{a^6}{r_{ij}^3}$$

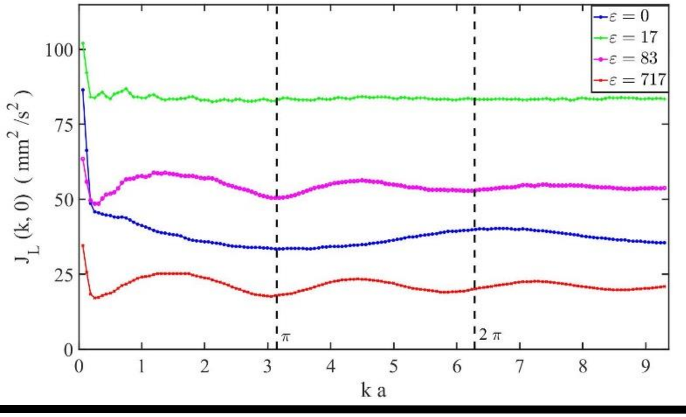
Competition between remote interactions vs agitation

Velocity fluctuations. Longitudinal current correlations in spatial Fourier space

$$J_l(\mathbf{k},t) = \left\langle \frac{1}{N} \sum_{i,j=1}^{N} (\hat{\mathbf{k}}\cdot\mathbf{v}_i(t))\,(\hat{\mathbf{k}}\cdot\mathbf{v}_j(0))\, e^{\imath\,\mathbf{k}\,(\mathbf{r_i}(t)-\mathbf{r_j}(0))} \right\rangle$$

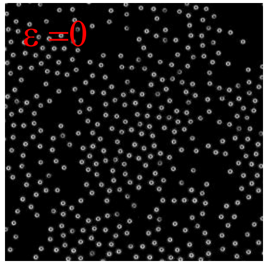
$$J_l(k,t) = (2\pi)^{-1} \int_0^{2\pi} J_l(\mathbf{k},t)\,\mathrm{d}\theta \quad \text{Isotropic average}$$

Kinetic longitudinal energy spectrum.
For ε=17, flat spectrum. **Equipartition.**

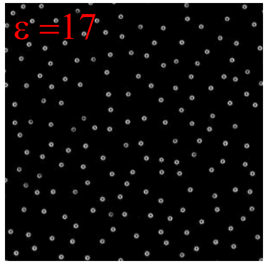


Different regimes as a function of ε:

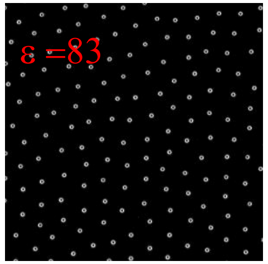
Granular gas (0 ≤ ε <10.7)



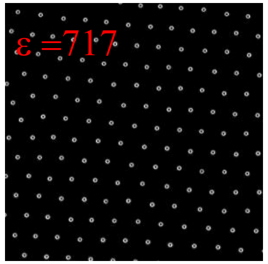
Dipole fluid (10.7 < ε < 21.9)



Partial order (21.9 < ε < 185)



Cristal (185 < ε < 1484)



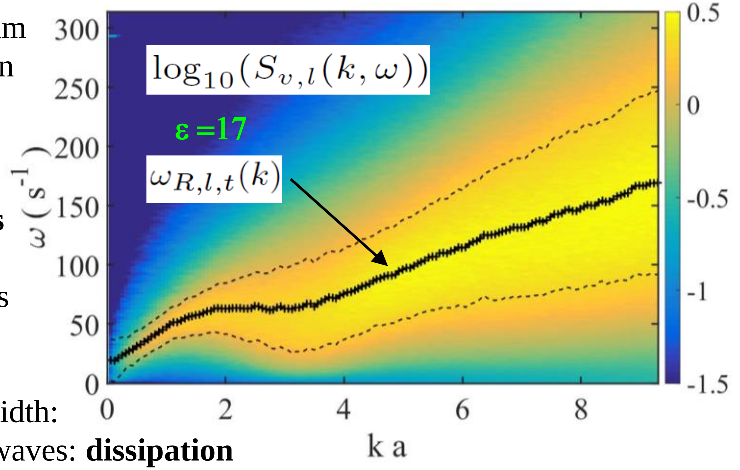
- Space-time spectrum of longitudinal kinetic energy

$$S_{v,l}(k,\omega) = \mathrm{Re} \int_0^{\infty} \int_0^{2\pi} J_l(\mathbf{k},t)\, k\, \mathrm{d}\theta\, e^{\mathrm{i}\omega t}\, \mathrm{d}t$$

Maxima of spectrum defines a dispersion relation $\omega_R(k)$

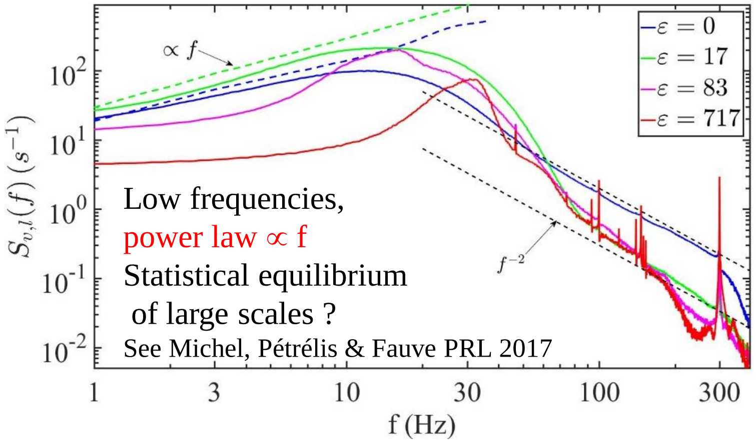
Propagation of **mechanical waves** analog to compression waves in fluids.

Significant R.D. width: small life time of waves: **dissipation**



- Deducing the **time spectrum** from the space spectrum from the experimental dispersion relation

$$S_{v,l}(f) = 2\pi/(\partial\omega_{R,l}/\partial k)\, k_R(f)\, S_{v,l}(k)$$



- Large frequencies and low ε: power law ∝ f^2 , to investigate maybe related to the life time of excitations.

- Random dispersive waves + Nonlinear potential: ingredients of wave turbulence: “granular” turbulence?

- Homogeneous forcing in k-space, filtered by the wave dynamics. No well defined scale for energy injection.

- Analogy with dissipative turbulence in active matter
  See R. Alert, J.F. Joanny and J. Casademunt Nat. Phys.2020