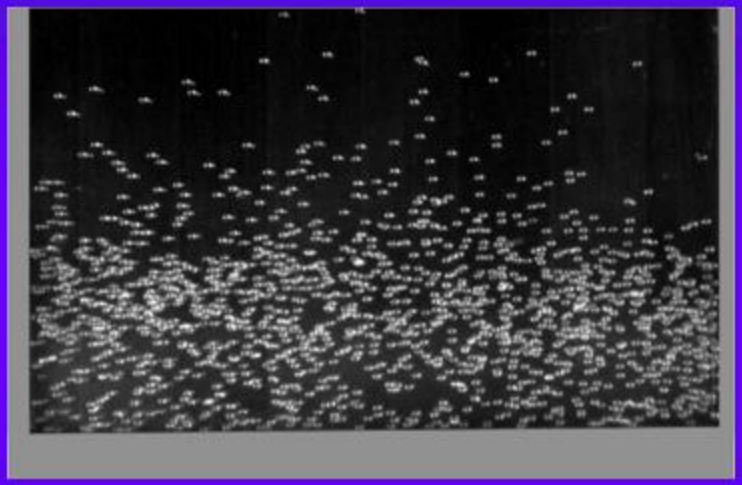
Phase Diagram of Vertically Shaken Granular Matter



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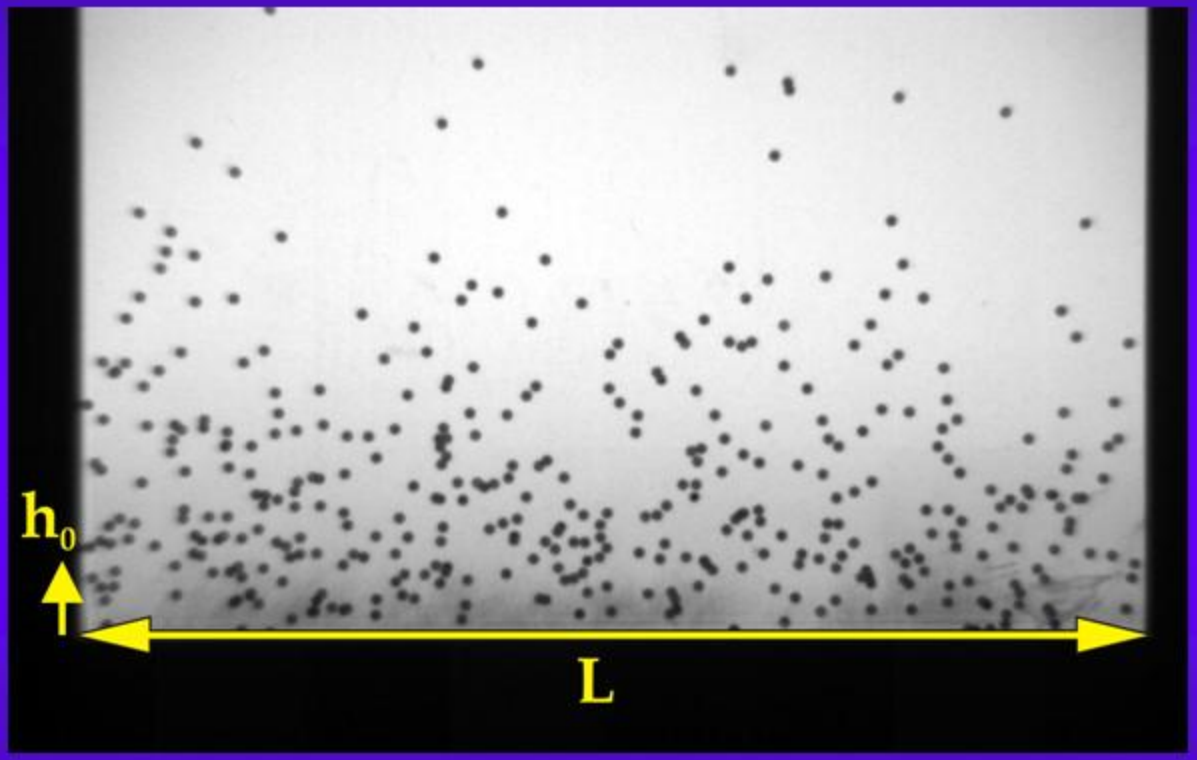
Quasi 2-D container

$L \times D \times H$ = 101 x 5 x 150 mm



- Glass beads: d =1.0 mm, $e \approx 0.95$
- Frequency f linearly increased, amplitude a fixed

What are the dimensionless control parameters?

(i) Shaking parameter: $\dfrac{a^2\omega^2}{g\ell}$ $(\omega = 2\pi f,\ g = 9.81\,\mathrm{m/s^2})$

- *Mild* fluidization: $\ell \propto a \Rightarrow \dfrac{a\omega^2}{g} = \Gamma$

- *Strong* fluidization: $\ell \propto d \Rightarrow \dfrac{a^2\omega^2}{gd} \equiv S$

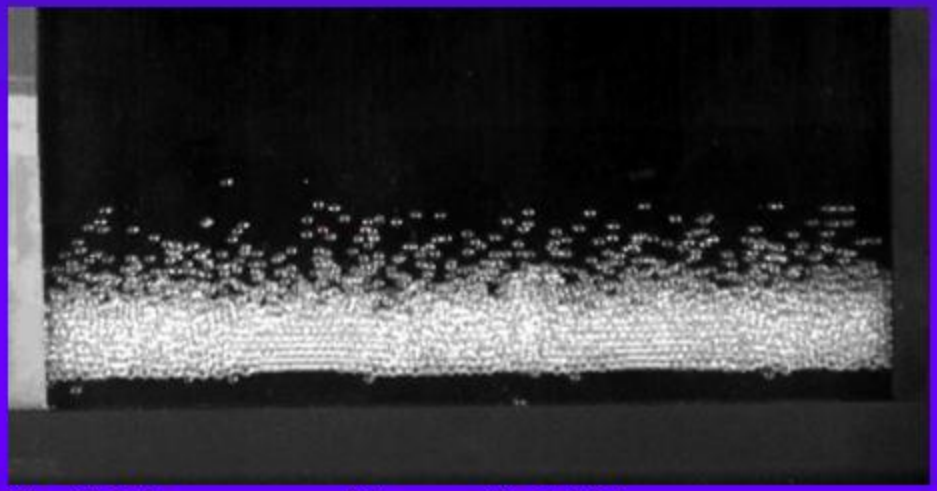
!

(ii) Number of particle layers: F

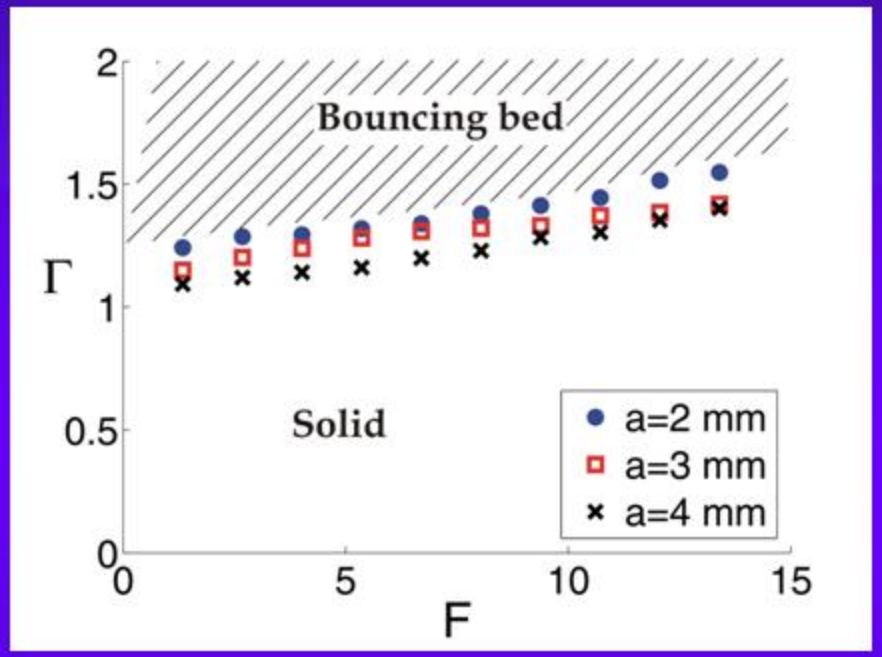
(iii) Inelasticity: $\varepsilon = (1 - e^2) = \text{constant}\ \ (\approx 0.1)$

(iv) Aspect ratio: $\dfrac{L}{h_0}$ remains large $(h_0 = \text{bed height at rest})$

1. Bouncing bed



$F = 8.1$ layers, $a = 4.0$ mm, $f = 12$ Hz

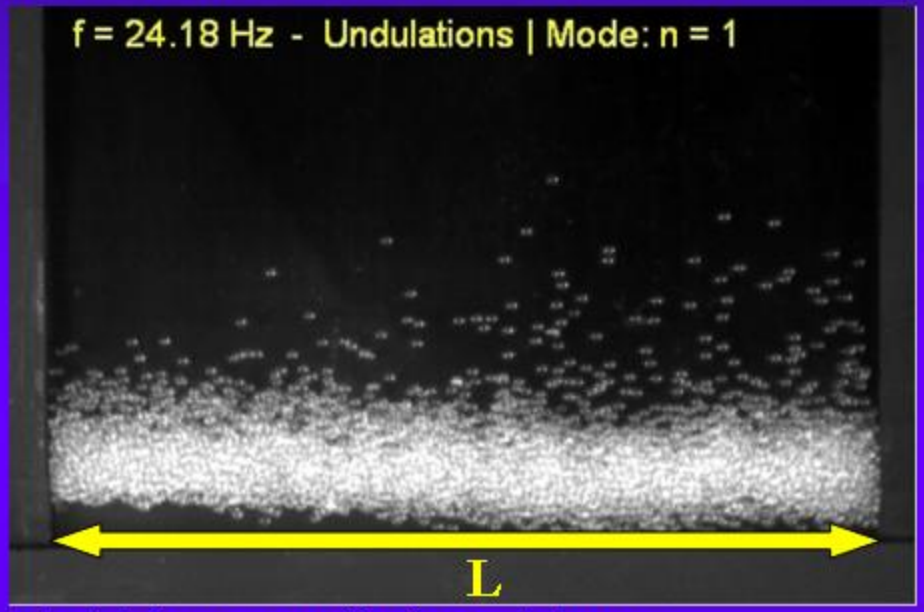


The granular bed bounces as a single body

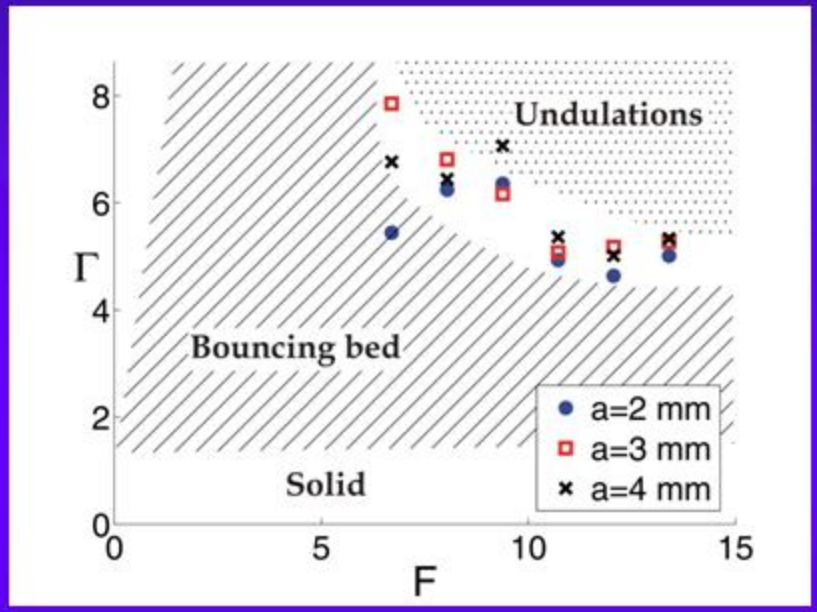
Mild fluidization → Γ

Mehta and Luck, *Phys. Rev. Lett.* **65**, 393 (1990)

2. Undulations



$F = 8.1$ layers, amplitude $a = 3.0$ mm

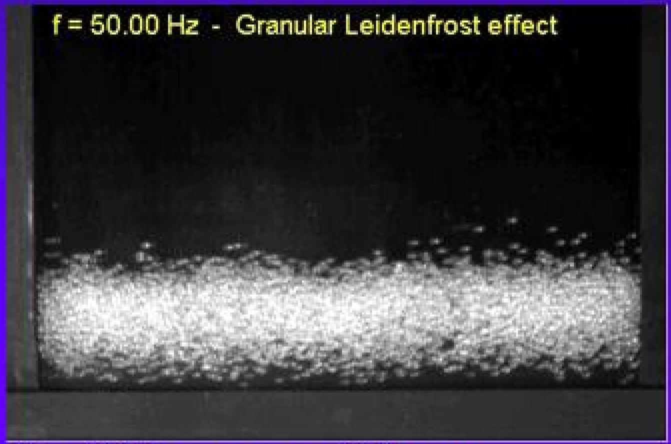


Standing wave pattern oscillating at 2T

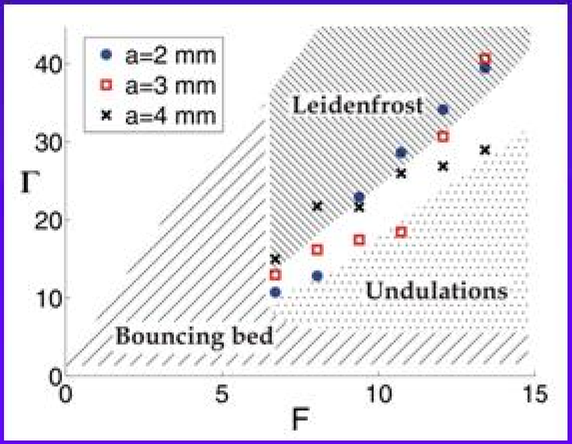
Mild fluidization → Γ

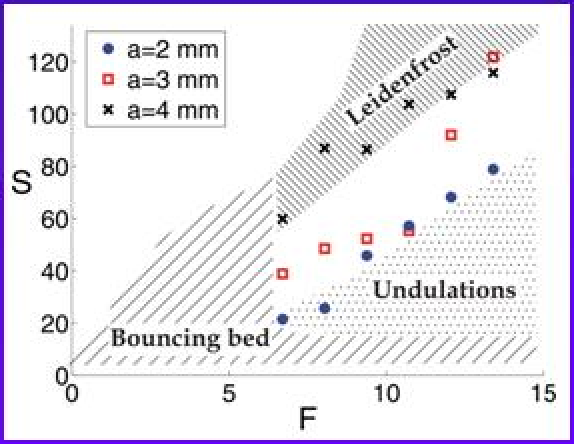
Sano, *Phys. Rev. E* **72**, 051302 (2005)

3. Granular Leidenfrost effect



$F = 8.1$ layers, $a = 3.0$ mm



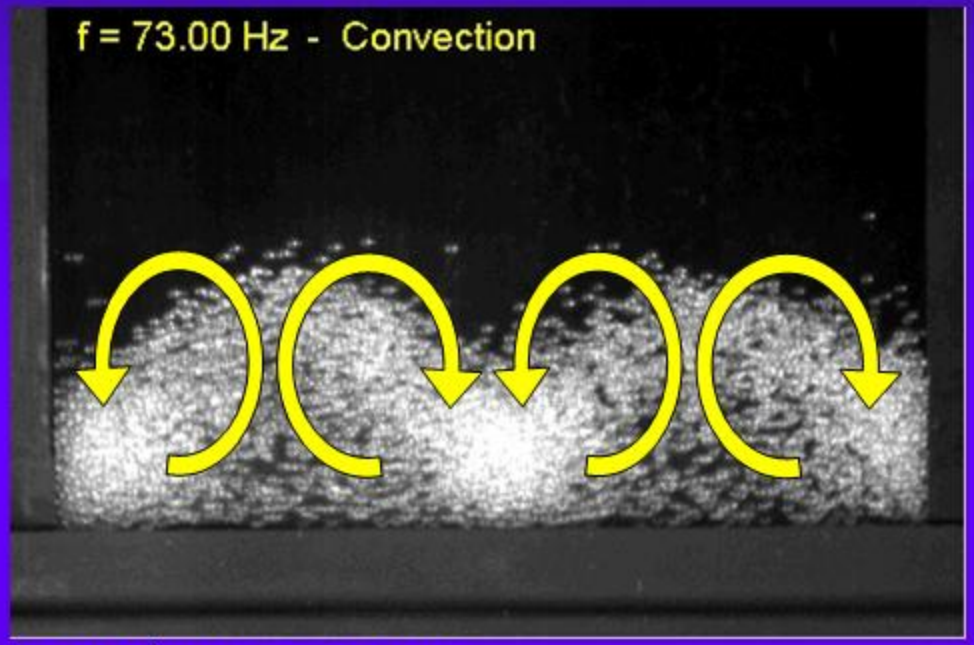


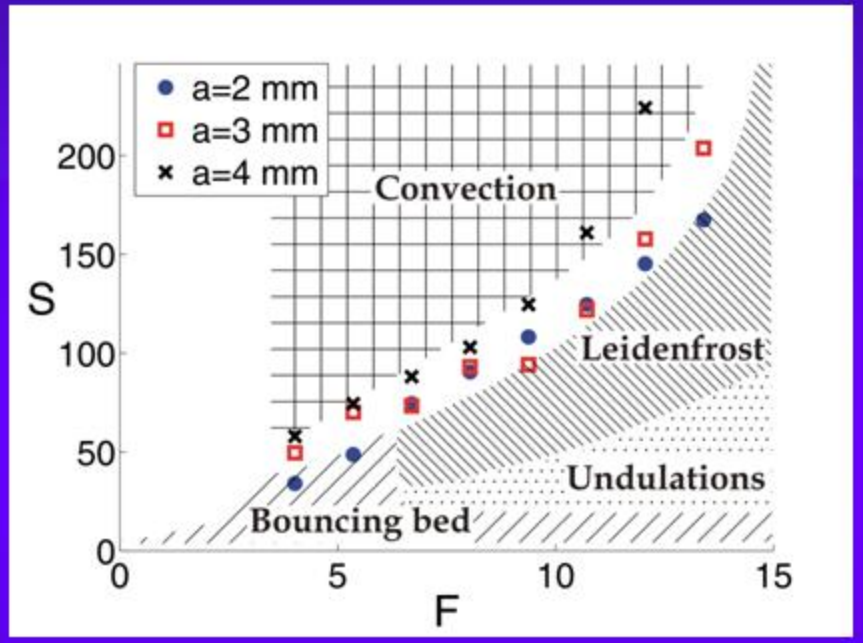
Dense cluster elevated by dilute layer of fast particles

Intermediate fluidization: both Γ and S → Candidates…

Meerson *et al.*, *Phys. Rev. Lett.* **91**, 024301 (2003)
Eshuis *et al.*, *Phys. Rev. Lett.* **95**, 258001 (2005)

4. Convection





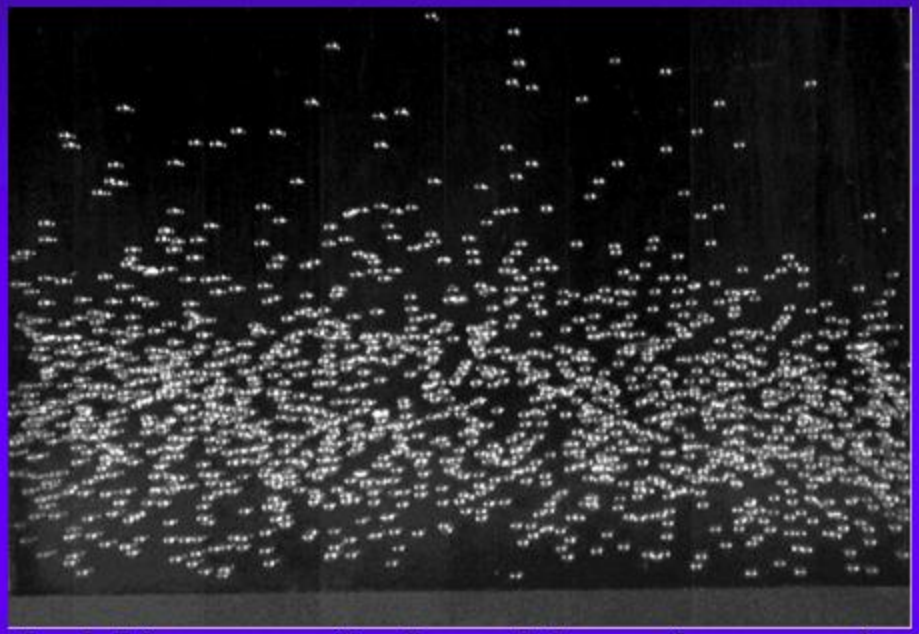
$F = 8.1$ layers, $a = 3.0$ mm

Counter-rotating rolls like Rayleigh-Bénard convection

Strong fluidization → S

Paolotti *et al.*, *Phys. Rev. E* **69**, 061304 (2004)

5. Gas

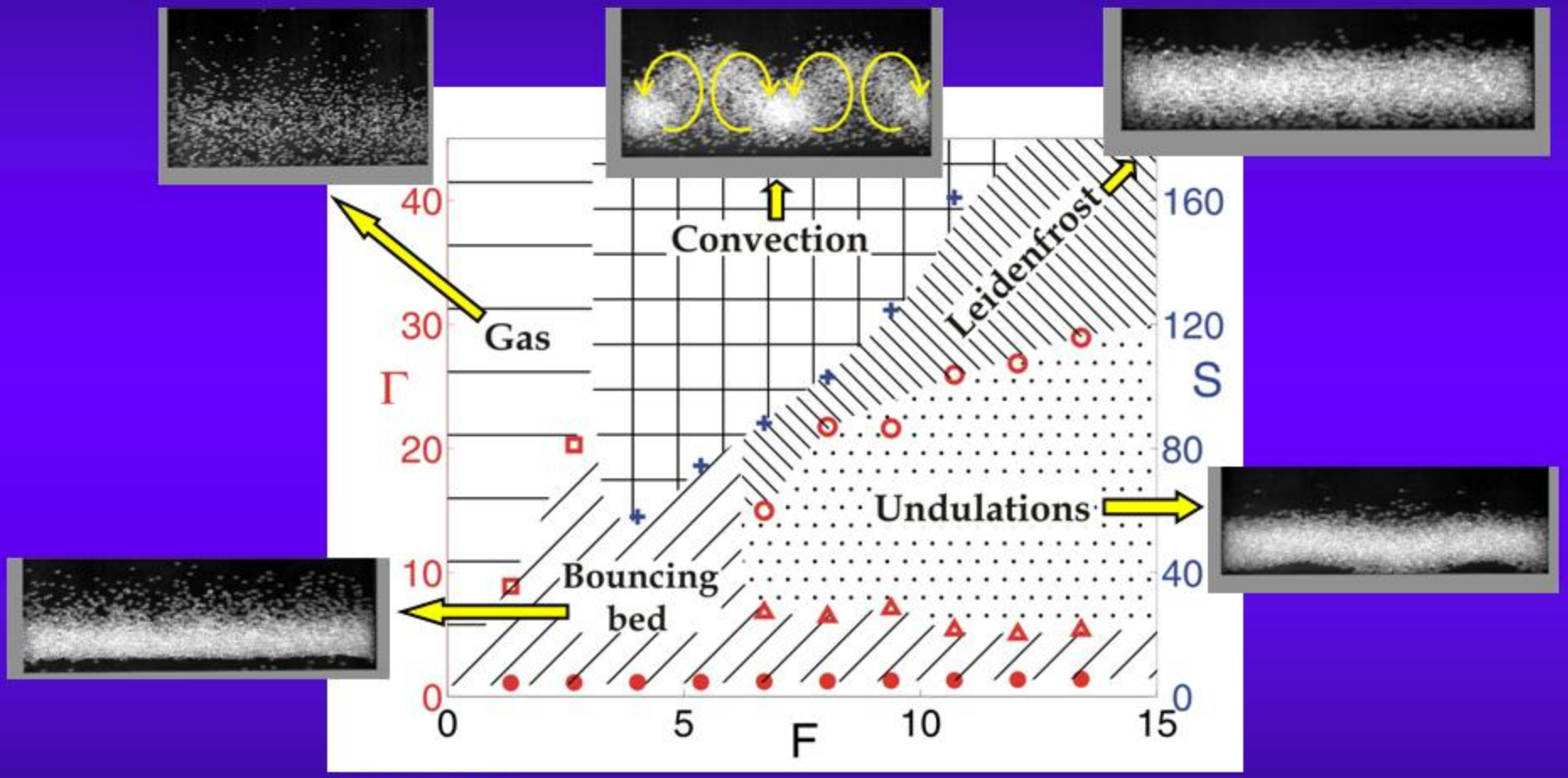


$F = 2.7$ layers, amplitude $a = 3.0$ mm, frequency $f = 50$ Hz

Shaking parameter → either Γ (from bouncing bed) or S (from convection)

Grossman *et al.*, *Phys. Rev. E* **55**, 4200 (1997)

Conclusion



a = 4.0 mm

P. Eshuis, K. van der Weele, D. van der Meer, R. Bos, and D. Lohse, *"Phase Diagram of Vertically Shaken Granular Matter"*, preprint ArXiv.org: physics/0608283 (2006)