Unjamming dynamics of a granular seismic model

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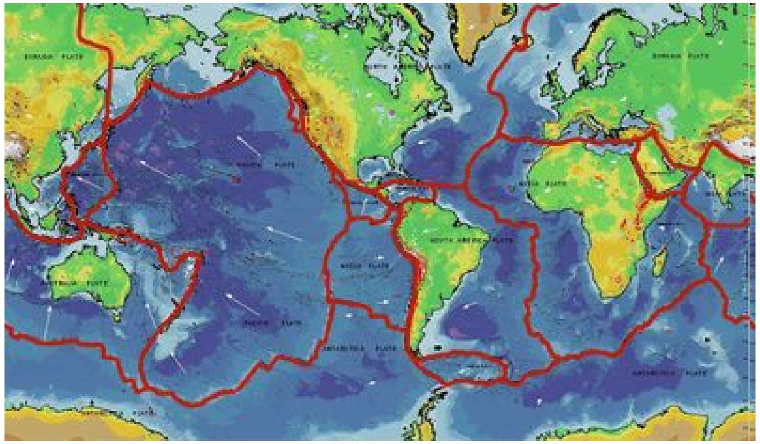
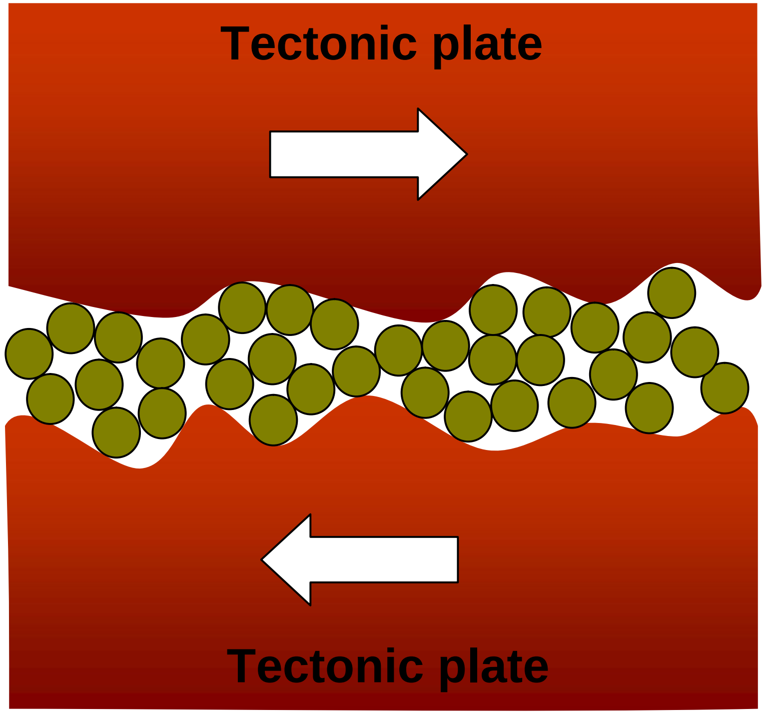
M. Pica Ciamarra, E. Lippiello, C. Godano, L. de Arcangelis, PRL **104**, 238001 (2010);
M. Pica Ciamarra, E. Lippiello, L. de Arcangelis, C. Godano, EPL **95**, 54002 (2011)
M. Pica Ciamarra, A. Coniglio, Phys. Rev. Lett. **103**, 235701 (2009)



Earthquake:

Shear stress induced transition from a disordered solid (jammed) to a flowing state (unjammed) in a granular assembly



Seismic fault

(normal fault)

Fault gouge
"Breccia di faglia"

Granular particles, product of wearing

The shear stress is supported by the granular particles

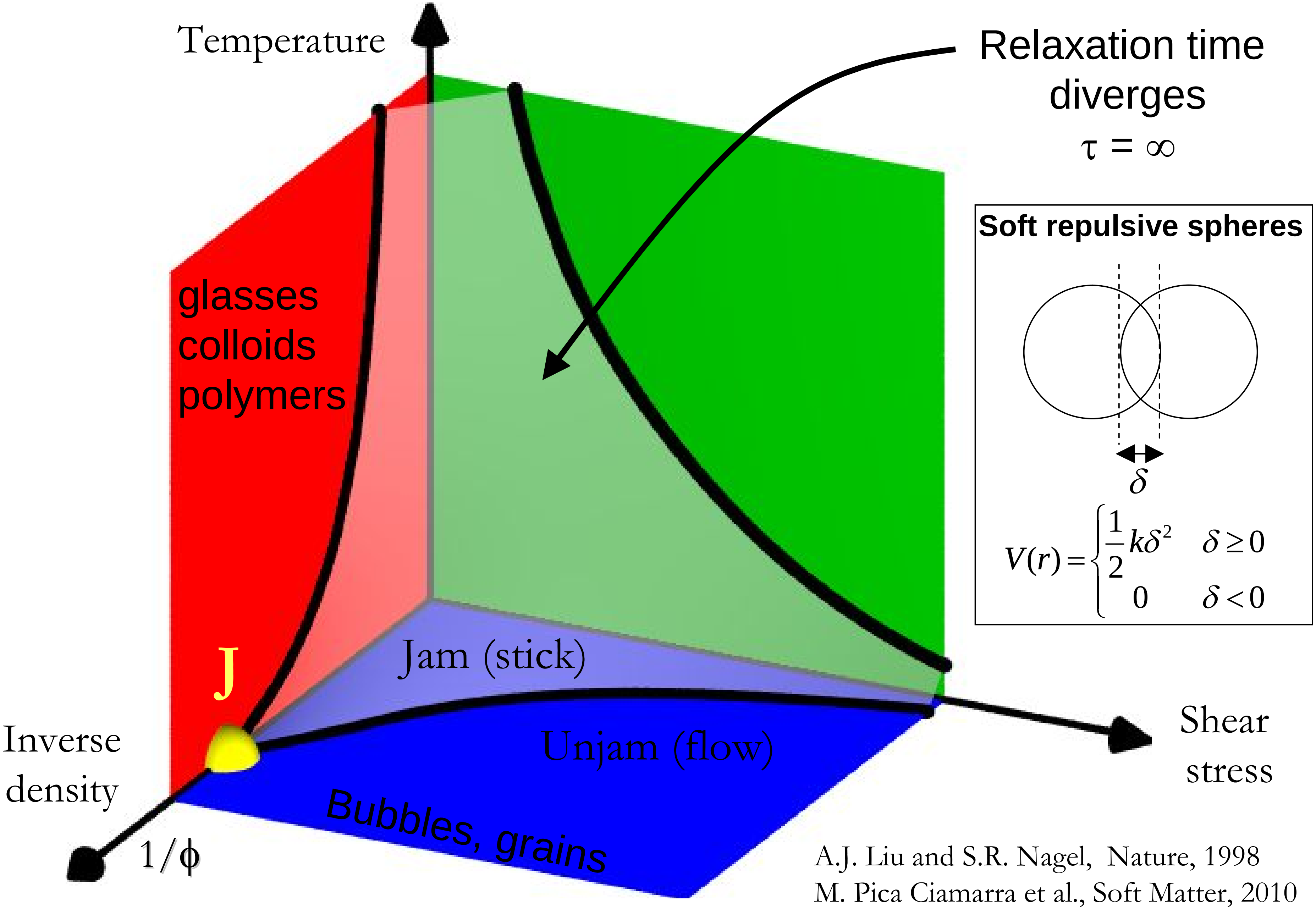
In this talk:

- Jamming transition at point-J
  - Geometrical and structural properties
  - Existence of a diverging length scale

    M. van Hecke, J. Phys.: Condens. Matt., 2010

- Length scale at finite applied shear stress?
  - Model system
  - Failure as an emerging process
  - Response to perturbations

Jamming phase diagram

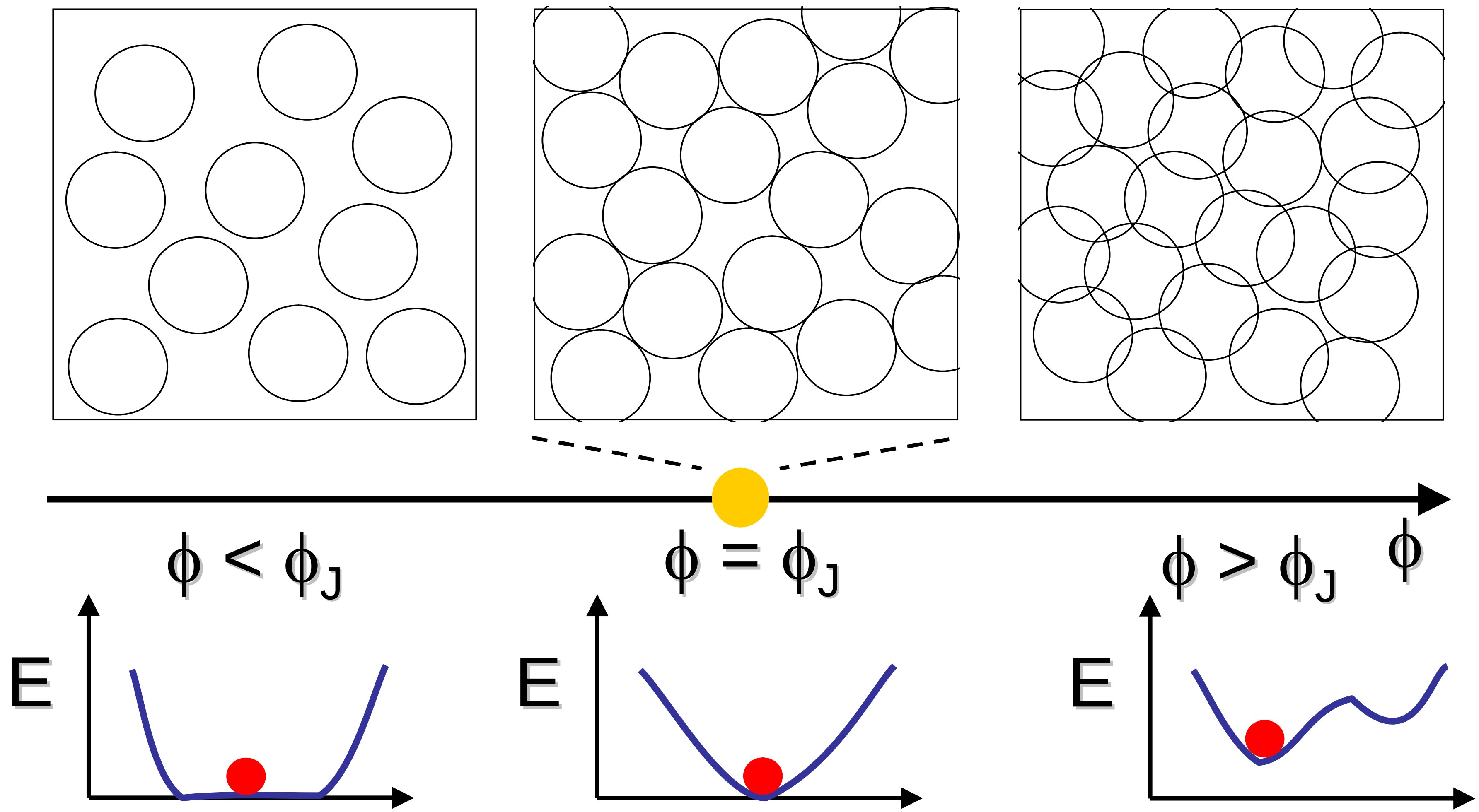


A.J. Liu and S.R. Nagel, Nature, 1998
M. Pica Ciamarra et al., Soft Matter, 2010

Jamming transition: point-J

Protocol: slowly compress frictionless soft spheres at zero temperature

C. O’Hern *et al.*, PRE 68, 011306 (2003);

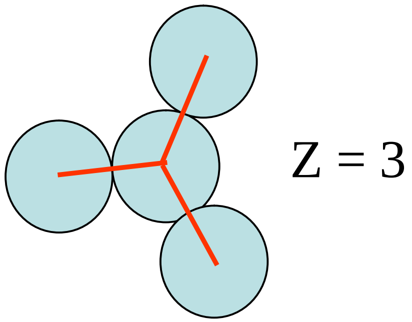


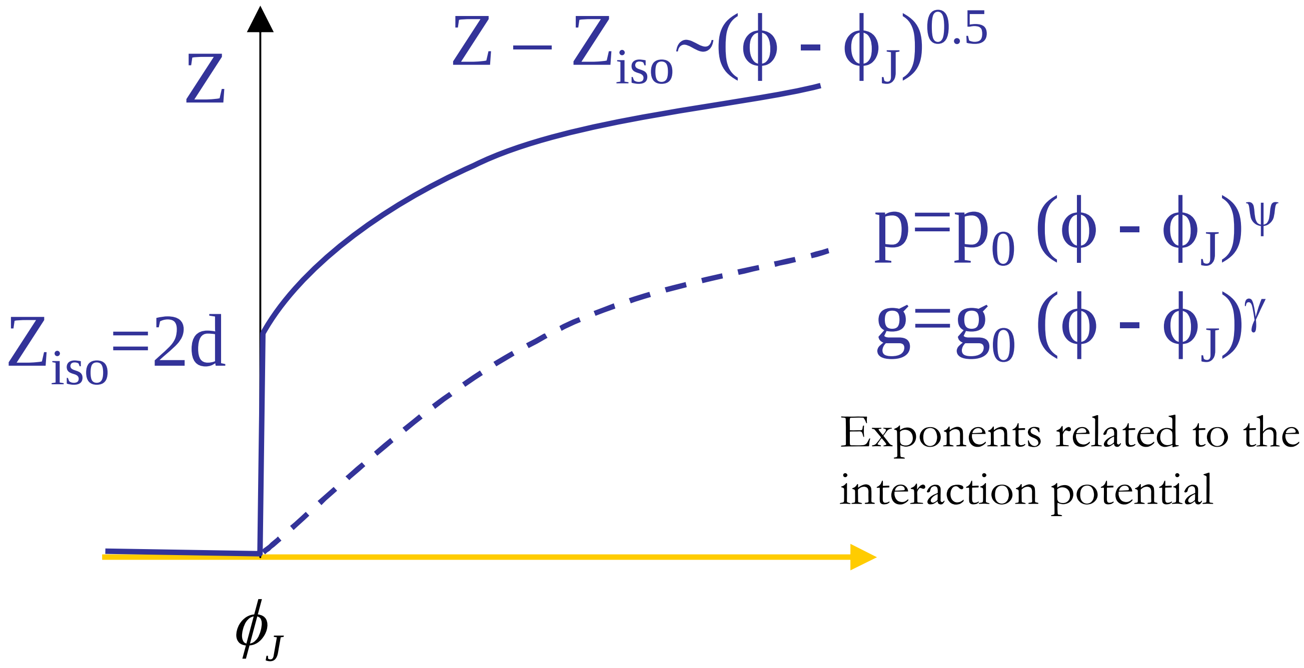
<u>Small protocol dependence</u>

M. Pica Ciamarra, A. Coniglio and A. de Candia, *Soft Matter*, **6**, 2975, 2010
P. Chaudhuri, L. Bethier, and S. Sastry, *Phys. Rev. Lett.* **104**, 165701, 2010
M. Hermes and M. Dijkstra, *Europhys. Lett.* **89**, 38005, 2010

Geometrical and mechanical transition

Mean contact number Z





Equilibrium of N grains in d dimensions

Number of equations: N d

Number of unknowns (forces): NZ/2

$$Nd = NZ/2 \rightarrow Z = Z_{iso} = 2d$$

$Z < Z_{iso}$ no solution

$Z = Z_{iso}$ one solution

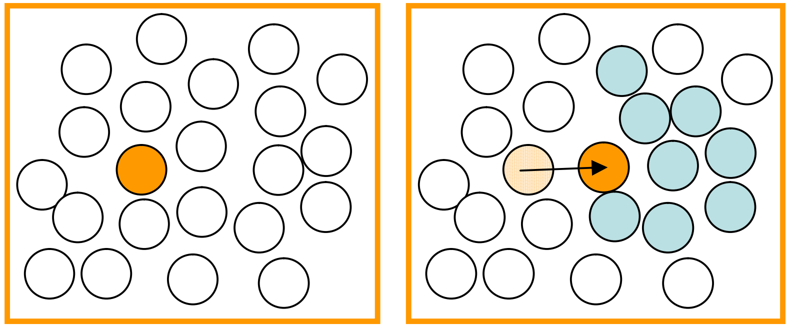
$Z > Z_{iso}$ many solutions

C. O'Hern *et al.*, PRE 68, 011306 (2003)

Diverging length below jamming, $\phi \to \phi_J$

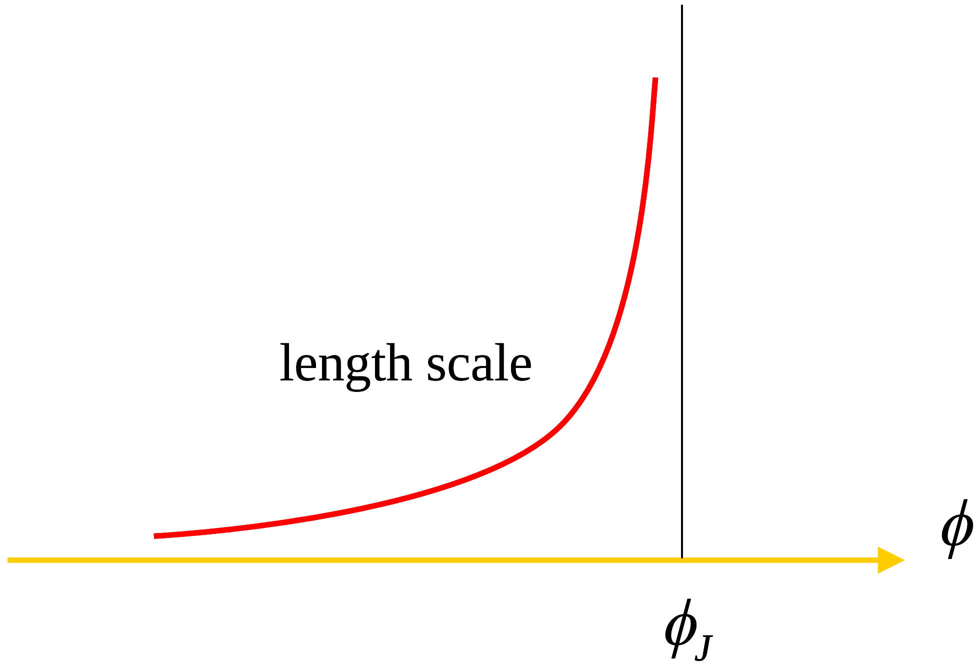
$\phi < \phi_J$

J.A. Drocco *et al*, PRL 95, 088001 (2005)



Cluster of co-moving particles
Cooperatively rearranging region

$\xi \sim (\phi_J - \phi)^{-0.65}$



P. Olsson, S. Teitl, PRL 99, 178001 (2007)

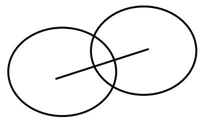
$\eta \sim (\phi_J - \phi)^{-1.65}$

$\xi \sim (\phi_J - \phi)^{-0.6}$

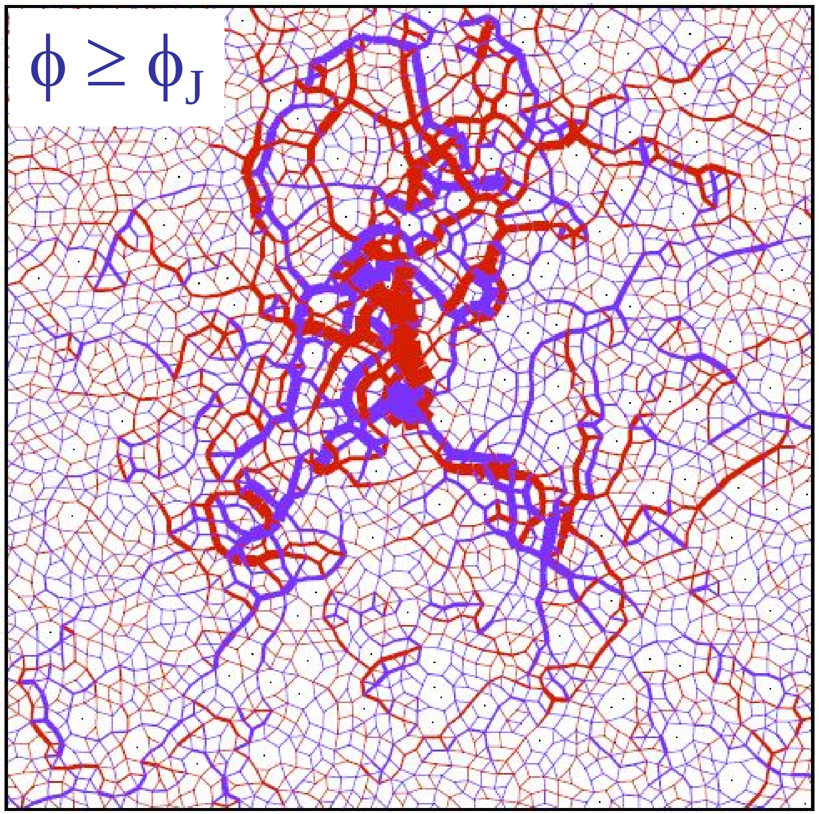
velocity correlations

Diverging length scale above jamming

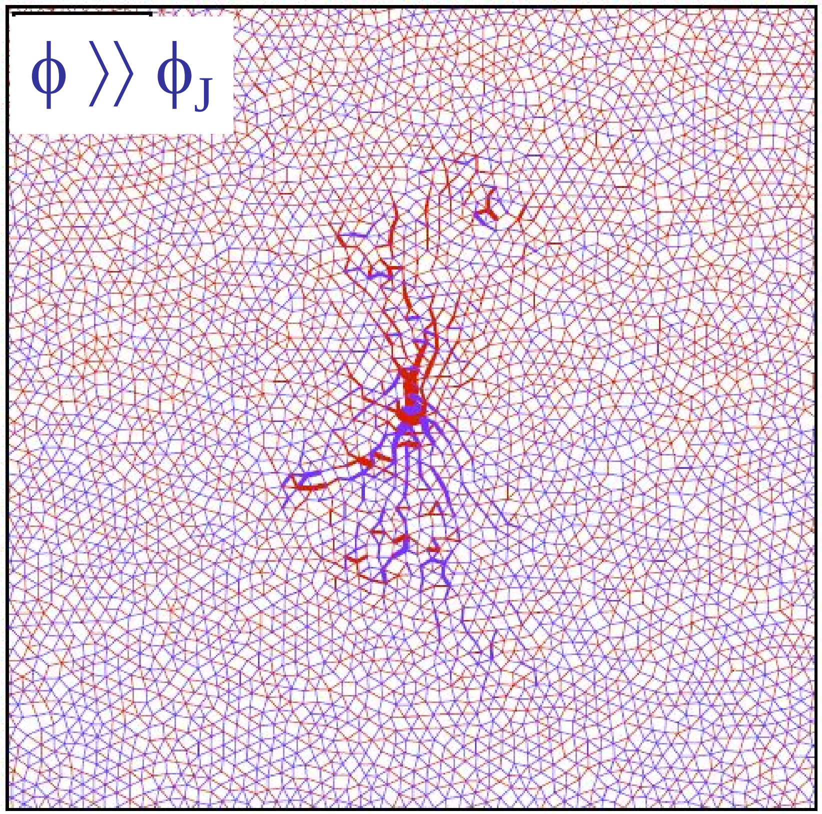
Response to perturbation: inflate the central particle; $\Delta D/D = 10^{-2}$



Just above jamming



Well above jamming



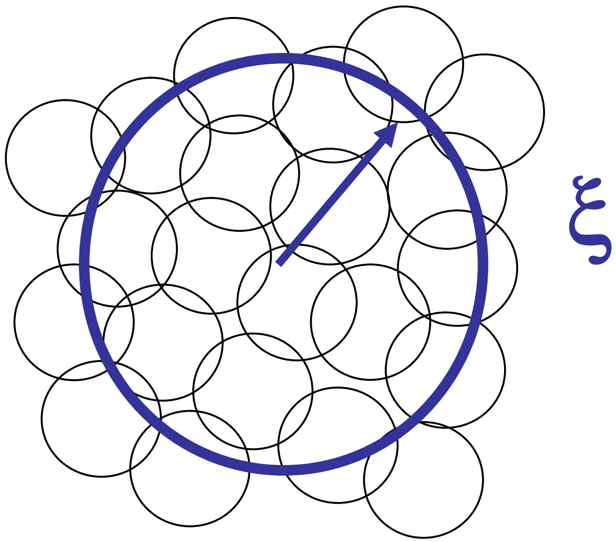
W.G. Ellenbroek, M. van Hecke, W. van Saarloos, Phys. Rev. E 80, 061307 (2009).

Diverging length above jamming, $\phi \to \phi_J$

$\phi > \phi_J$

Excess contacts: $\Delta Z = Z - Z_{iso} \sim (\phi - \phi_J)^{0.5} > 0$

Consider a blob of size ξ:

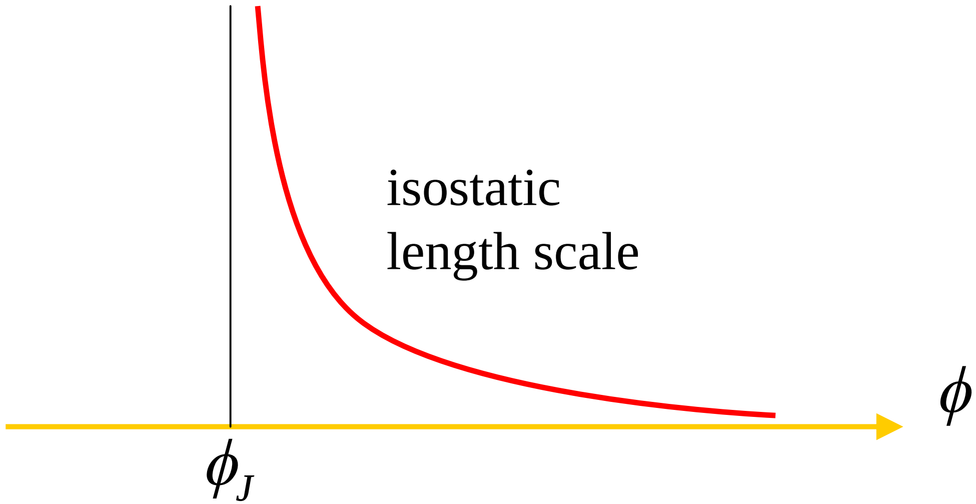


Excess contacts: $\propto \Delta Z \, \xi^d$

Surface contacts: $\propto Z \, \xi^{d-1}$

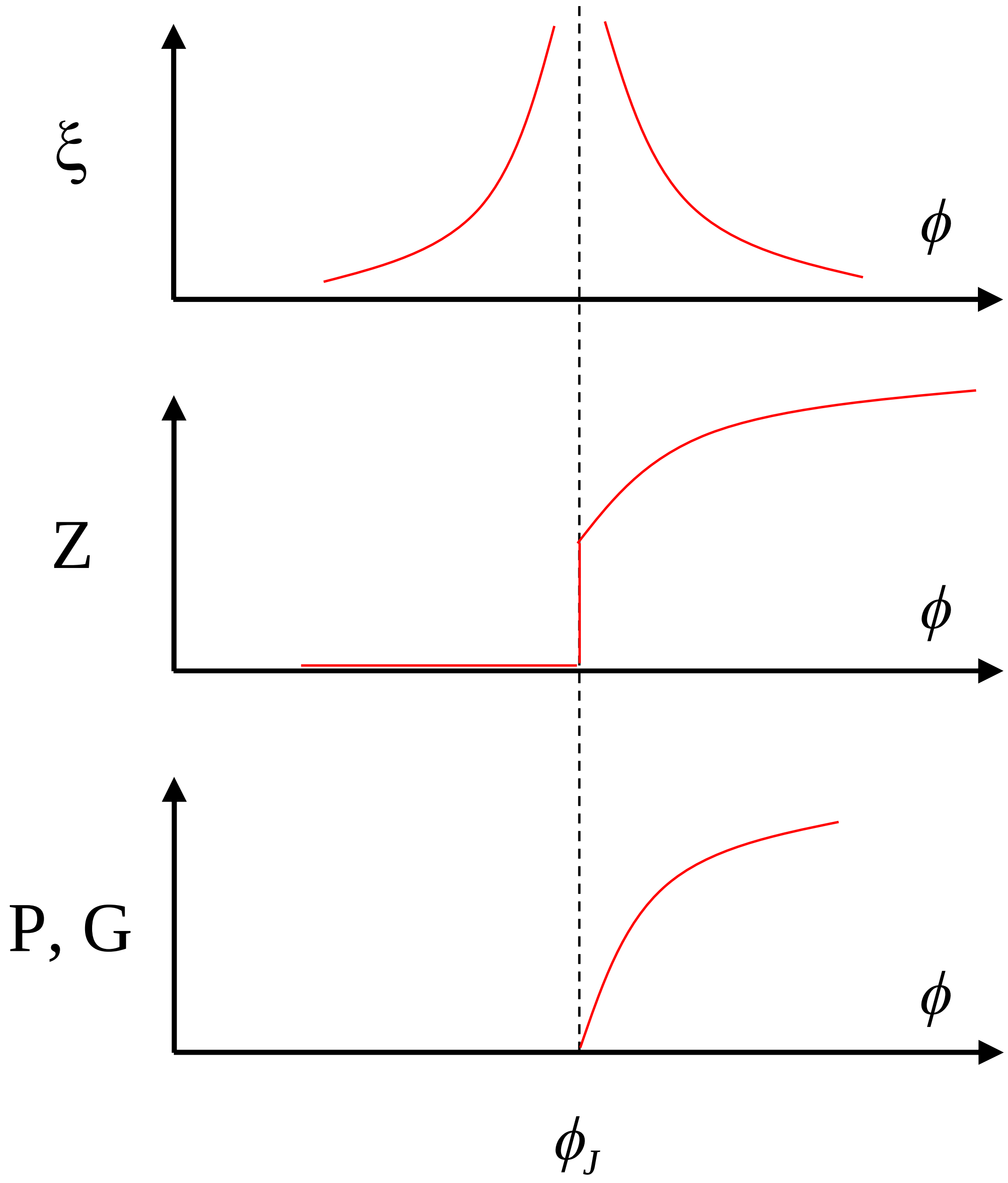
$$\Delta Z \, \xi^d \propto Z \, \xi^{d-1}$$

$$\xi \sim Z / \Delta Z \sim (\phi - \phi_J)^{-0.5}$$



M. Wyart *et al.*, Phys. Rev. E 72, 051306, 2005

Point-J: summary

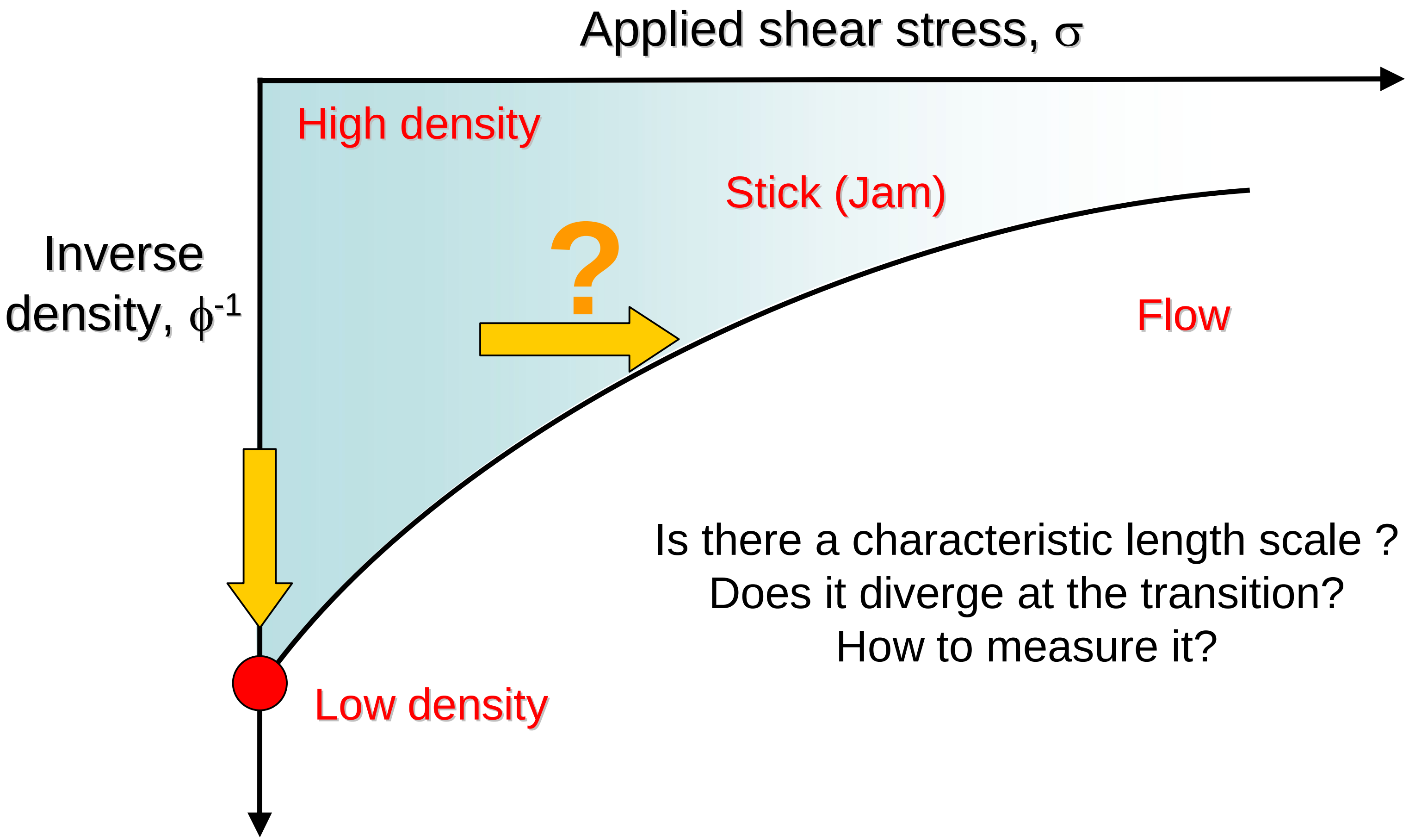


diverging
length scales

discontinuous
geometrical
properties

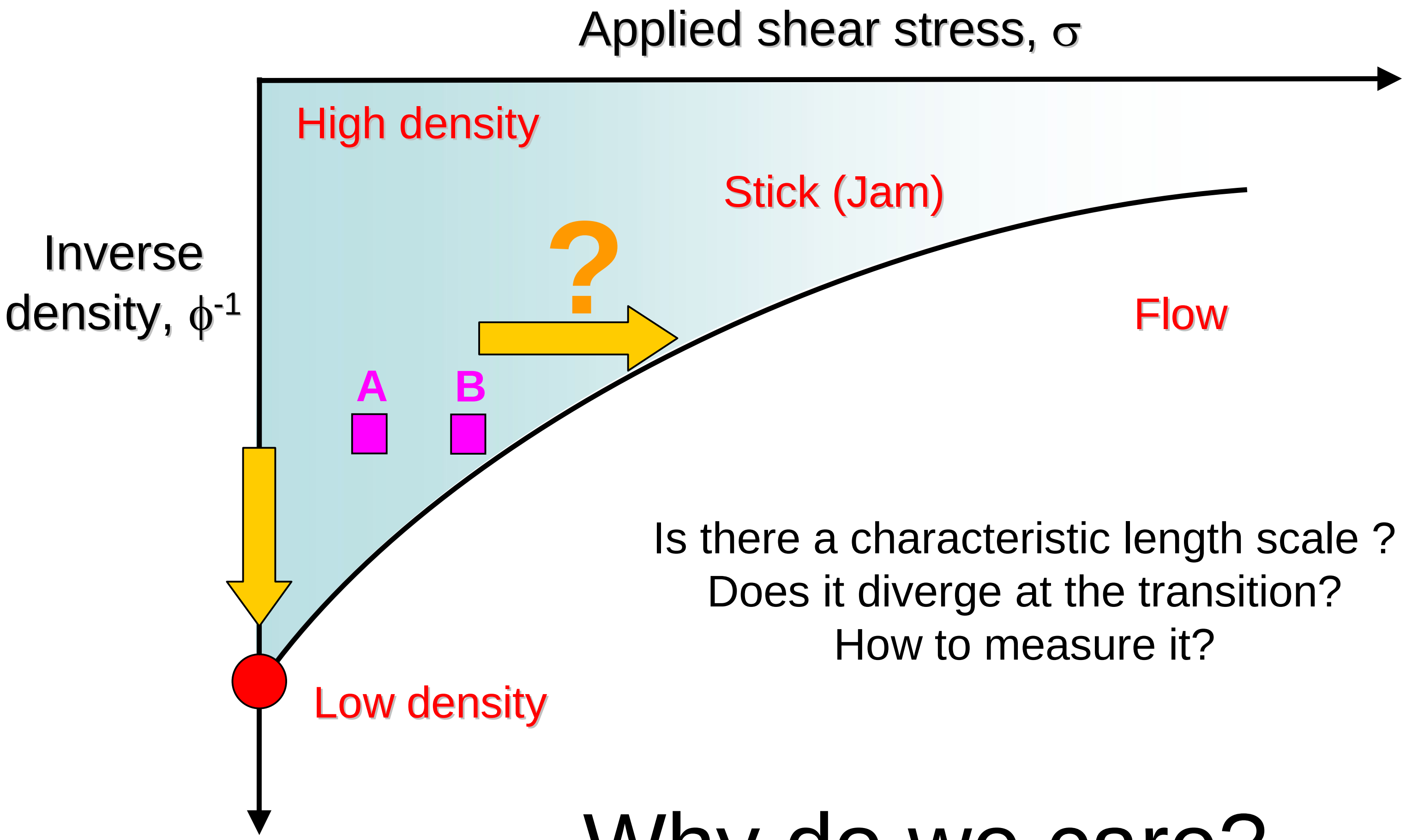
critical
mechanical
properties

Jamming at finite applied stress



Is there a characteristic length scale ?
Does it diverge at the transition?
How to measure it?

Jamming at finite applied stress

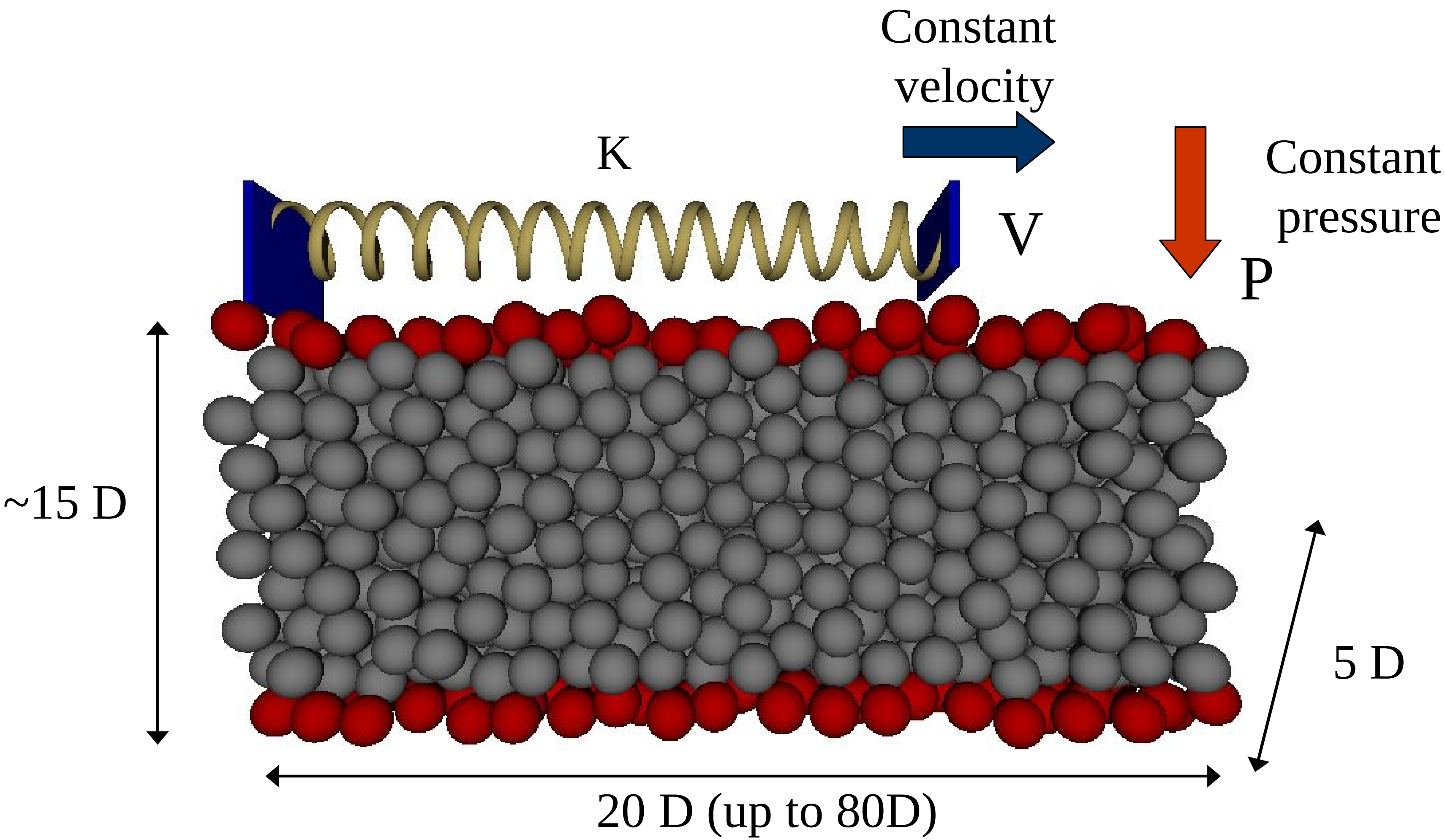


Is there a characteristic length scale ?
Does it diverge at the transition?
How to measure it?

Why do we care?
<u>Precursors</u>

we don' t known whereas the system is in state **A** or in state **B**

The model



Molecular Dynamics simulations of granular particles: friction, rotation

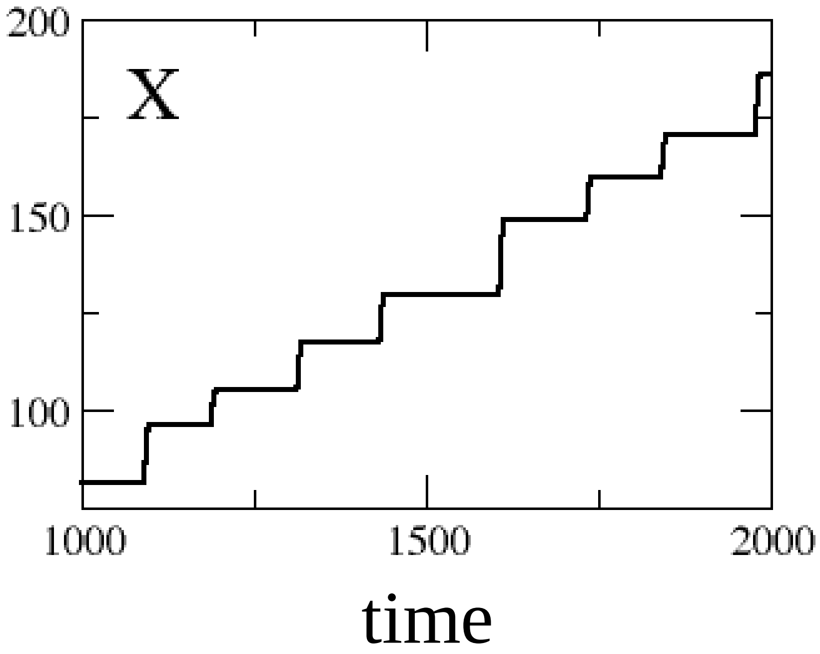
Reasonable model for earthquakes

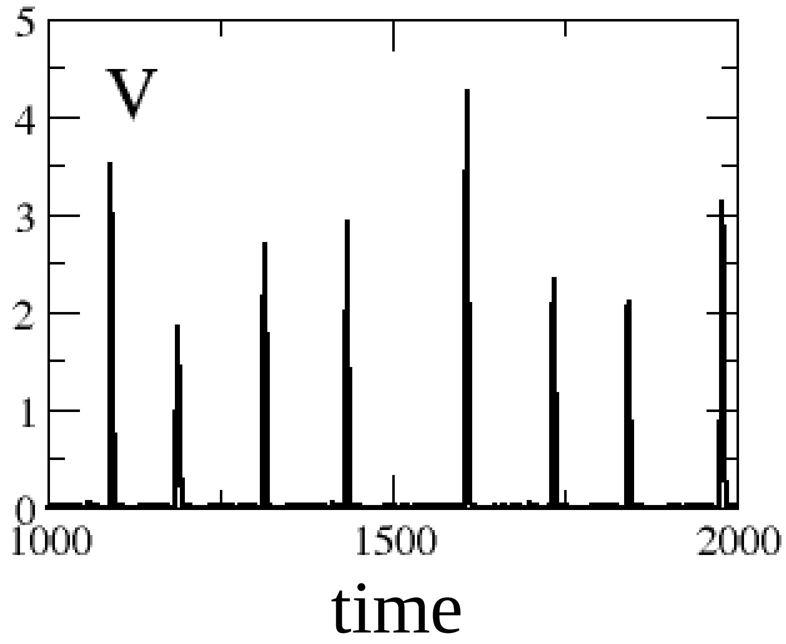
S. Nasuno et al. Phys. Rev. E 58, 2161 (1998)

E. Aharonov and D. Sparks, J. Geophys. Res. 109, B09306 (2004)

F. Dalton and D. Corcoran, Phys. Rev. E 63, 061312 (2001); Phys. Rev. E 65, 031310 (2002)

See poster by Alberto Petri

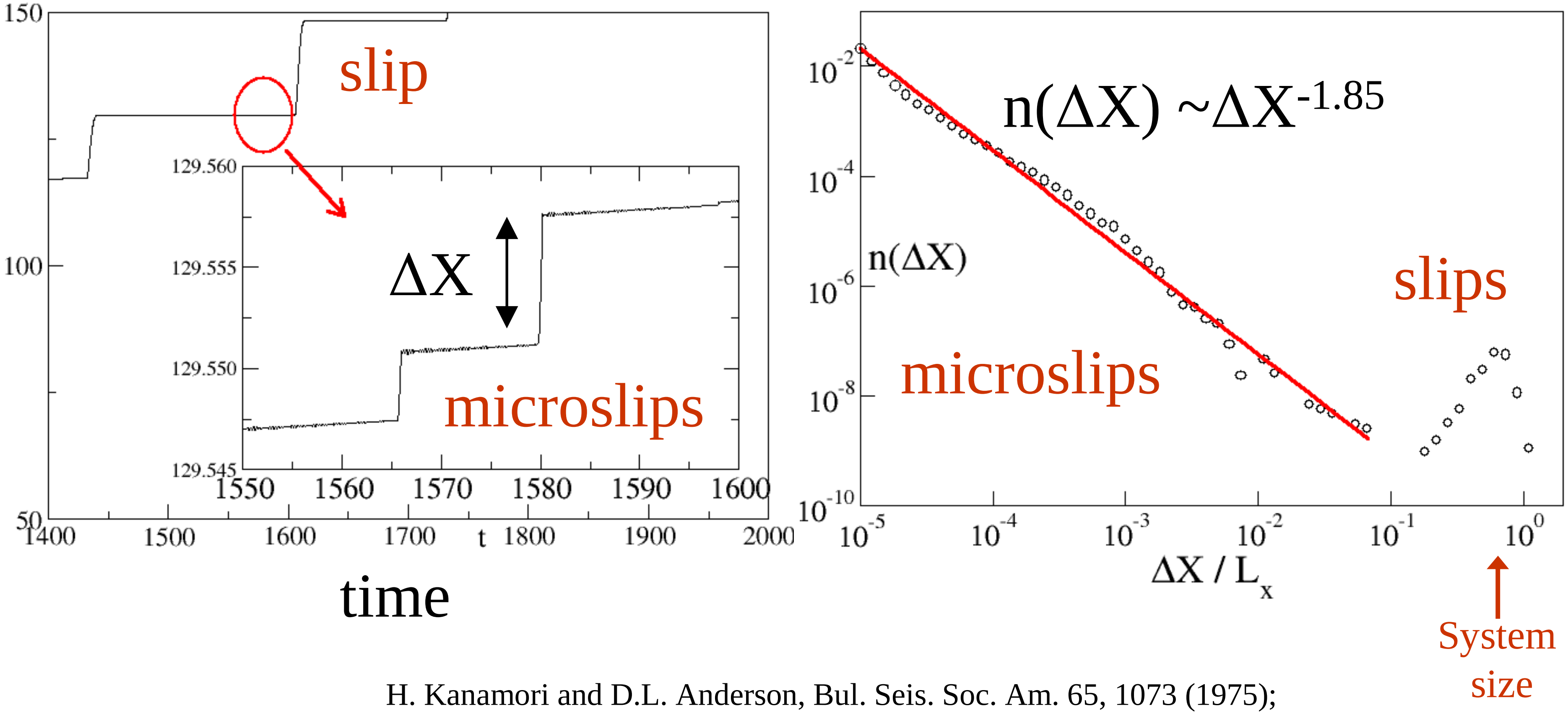




Quasi-regular slips + microslips

The model reproduces the Gutember Ritcher law

Very robust exponent:
system size, friction, inertia, rotation, drive



H. Kanamori and D.L. Anderson, Bul. Seis. Soc. Am. 65, 1073 (1975);

Y.Y. Kagan, Geophys. J. Int. 106, 123 (1991);

F. Dalton and D. Corcoran, Phys. Rev. E 63, 061312 (2001); Phys. Rev. E 65, 031310 (2002)

Response to perturbations

1) Vary the normal pressure by a factor α: P →P(1- α)

2) Measure the asymptotic displacement of each particle

$$\Delta r_i\ (t) = \lim_{\tau\to\infty}\left[r_i^{\alpha}(t+\tau) - r_i^{0}(t)\right]$$

3) Compute the susceptibility

$$\chi_\alpha(t) = \frac{1}{\alpha P}\left[\frac{1}{N}\sum_i \left|\Delta r_i^{\alpha}(t)\right|^2\right]^{1/2}$$

Average particle displacement

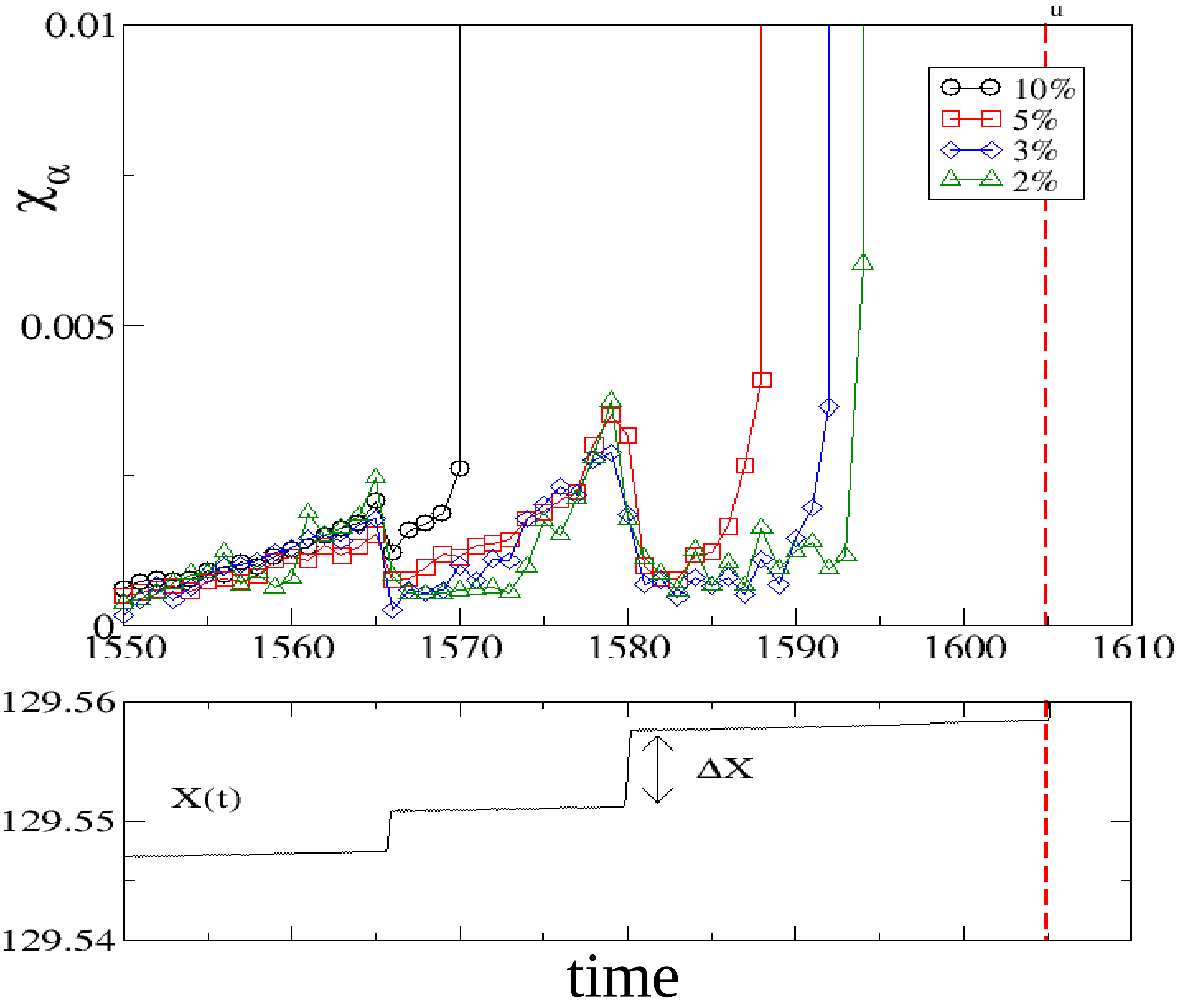
P.A. Johnson and X. Jia, Nature 437, 871 (2005).

P.A. Johnson, H. Savage, M. Knuth, J. Gomberg and C. Marone, Nature 451, 57 (2008).

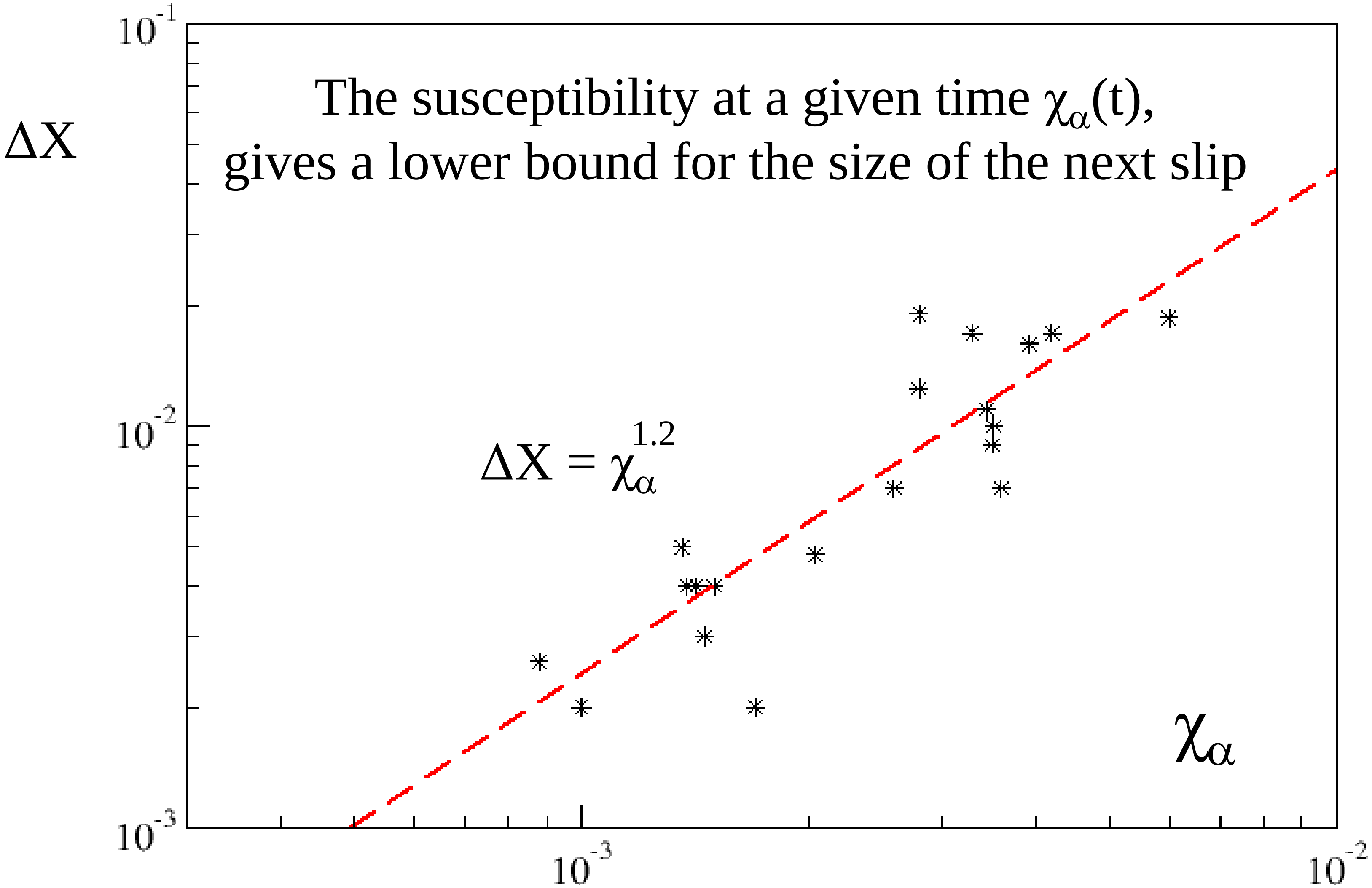
R. Capozza, A. Vanossi, A. Vezzani and S. Zapperi, Phys. Rev. Lett. 103, 085502 (2009).

Susceptibility

χ_α grows in correspondence to slips and microslips



Bound to the size of the next slip



Conclusions

Jamming transition at $\sigma = 0$

unjamming characterized
by a diverging length

Jamming transition at $\sigma > 0$, in a fault model

identified a growing susceptibility
related to the size of the slips

may open the way to the search for precursors

2 open positions