High-dimensional surprises near jamming: connecting spin glasses with reality

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MAX-PLANCK-INSTITUT FÜR PHYSIK KOMPLEXER SYSTEME, DRESDEN, GERMANY

International Workshop on

Particulate Matter: Does Dimensionality Matter?

31 May - 04 June 2010

Scientific coordination

Patrick Charbonneau, Duke University, Durham, USA

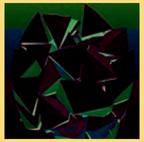
Karen Daniels, North Carolina State University, Raleigh, USA

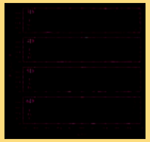
Matthias Schröter, MPI for Dynamics and Self-Organization, Göttingen, Germany

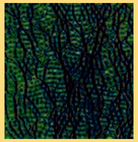
Organisation

Claudia Pönisch, MPI für Physik komplexer Systeme, Dresden, Germany

Colloids, granular materials, foams, hard spheres, and emulsions all provide insight into longstanding questions surrounding glass formation, packing, the role of confinement, and jamming. While only 2D and 3D systems are studied experimentally, theoretical investigations in higher dimensions help compare the statics and dynamics of corresponding phenomena. The aim of this workshop is to use the contrasts and similarities between these different dimensions and systems to identify root causes that are otherwise difficult to disentangle, and suggest novel lines of study.







Invited participants (* to be confirmed)

T. Aste (UK)
C. Bechinger (Germany)
R. Behringer (USA)
R. Blumenfeld (UK)
J. Brujic (USA)
H. Cohn (USA)
A. Coniglio (Italy)
S. Glotzer * (USA)
J. Kurchan (France)
H. Löwen (Germany)
H. Makse (USA)
N. Medvedev (Russia)
A. Mehta (India)
K. Miyazaki (Japan)
R. Mosseri (France)
C. O'Hern (USA)
C. Radin (USA)
P. Schall (Netherlands)
T. Schilling (Germany)
M. Sperl (Germany)
B. Tighe (Netherlands)
A. Tordesillas (Australia)
S. Torquato * (USA)
T. Truskett (USA)
M. van Hecke (Netherlands)
E. Weeks (USA)
E. Zaccarelli (Italy)
F. Zamponi (France)

Applications are welcome and should be made by using the application form on the workshop web page (please see URL below). The number of attendees is limited. The **registration fee** for the workshop is **100 €** and should be paid by all participants. Costs for accommodation and meals will be covered by the Max Planck Institute. Limited funding is available to partially cover travel expenses. Please note that childcare is available upon request.

Deadline for applications is 20 March 2010.

For further information please contact:
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MPIPKS also encourages applications for individual fellowships (phd,postdoc,sabbatical). We offer an exciting and stimulating environment for pursuing cutting-edge research, with about 120 researchers in residence at any time. With four deadlines per year, we accept applications continuously. For details, please check http://www.pks.mpg.de/visitors

Dimensional collaborators

Carolina Brito (Porto Alegre)
Benoit Charbonneau (Waterloo)
Eric Corwin (Oregon)
Daan Frenkel (Cambridge)
Andrea Fortini (Bayreuth)
Atsushi Ikeda (Montpellier)
Jorge Kurchan (ENS Paris)
Kunimasa Miyazaki (Nagoya)
Koos van Meel (Vienna)
Giorgio Parisi (La Sapienza)
Gilles Tarjus (UPMC)
Pierfrancesco Urbani (CEA)
Francesco Zamponi (ENS Paris)

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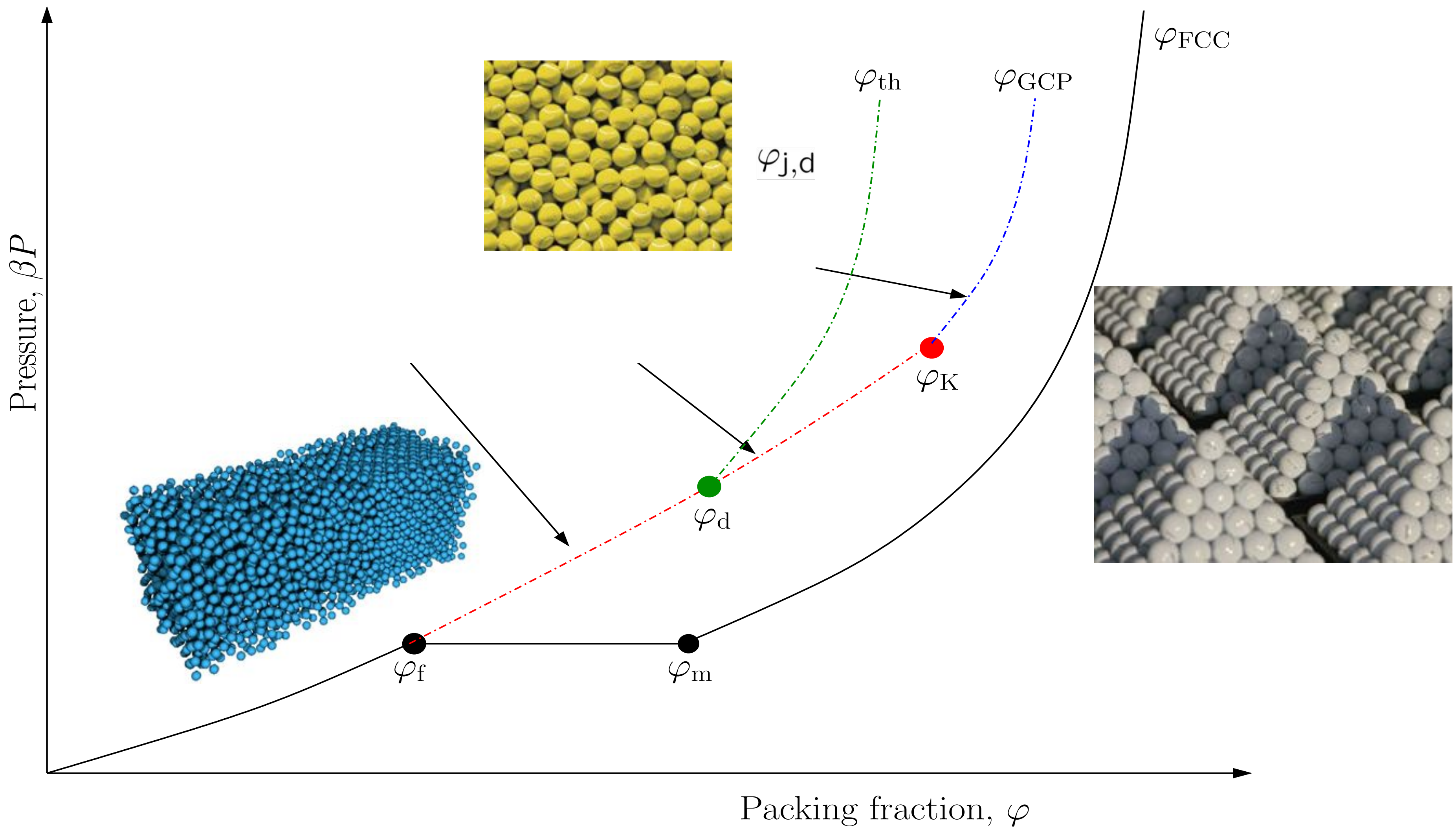
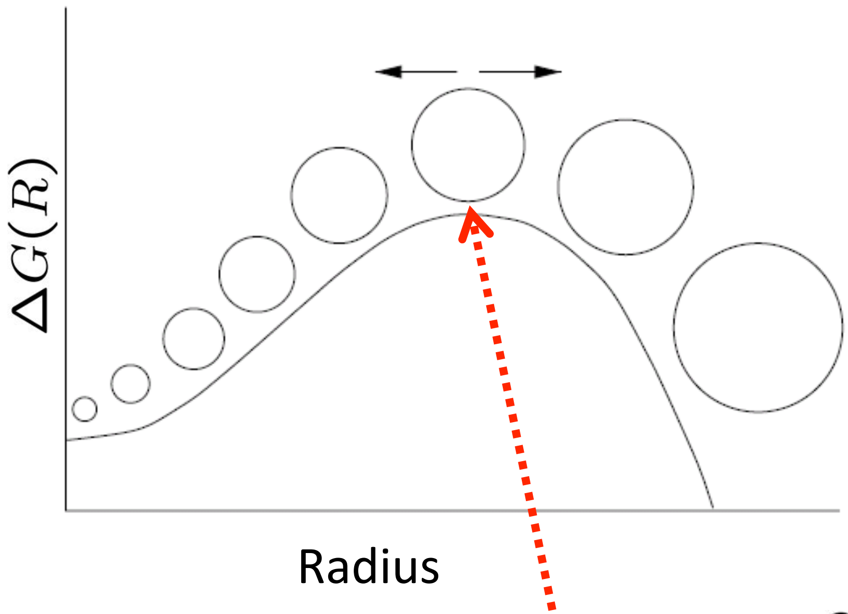
Prehistory: HS crystallization

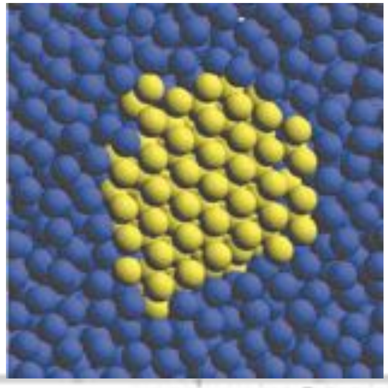


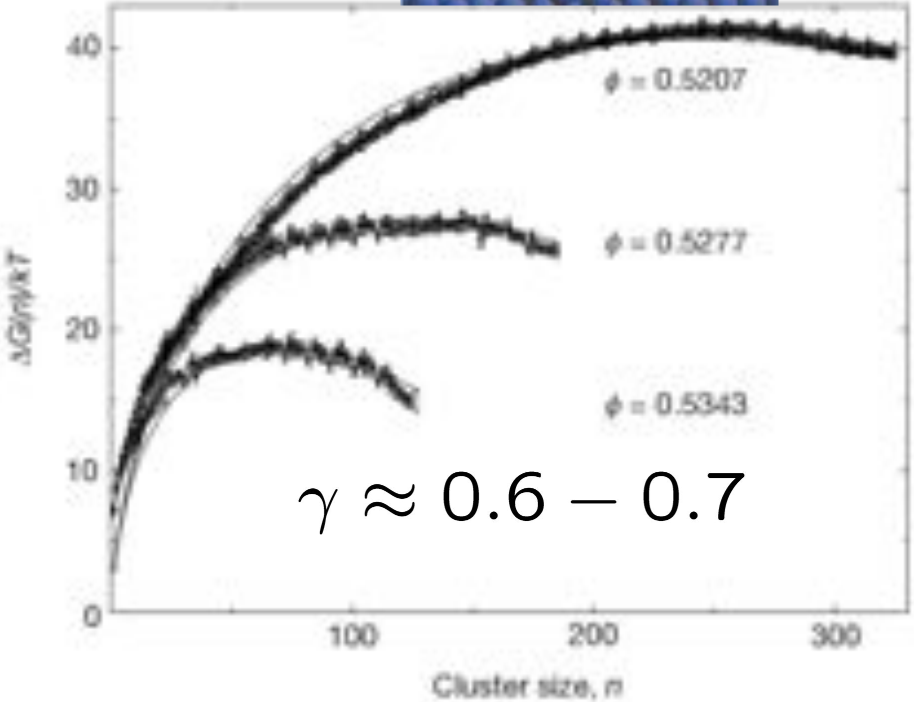
Homogeneous crystal nucleation

$$\Delta G(R) = \gamma 4\pi R^2 - \Delta\mu\rho_s \frac{4}{3}\pi R^3$$



$$\Delta G^{\dagger}(R^*) = \frac{16\pi\gamma^3}{3(\Delta\mu)^2}$$

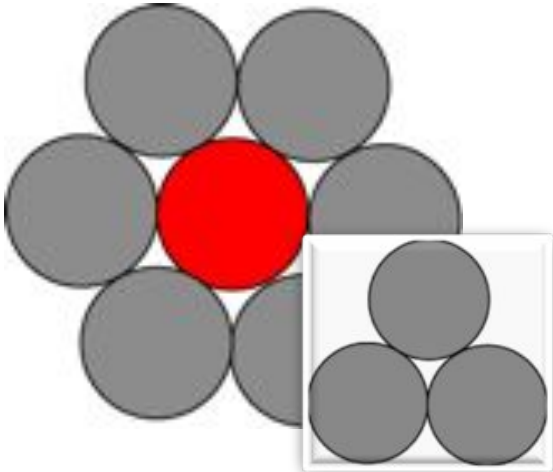




$\gamma \approx 0.6 - 0.7$

Auer and Frenkel, Nature (2002)

Geometrical frustration

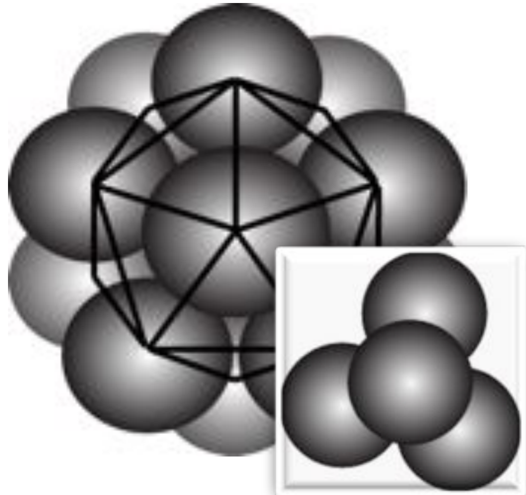


triangular lattice

2-simplex (triangle)

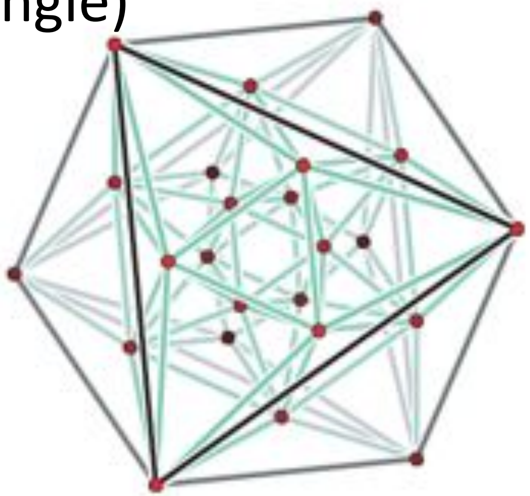
FCC lattice

vs.



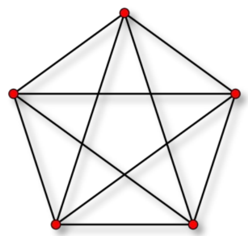
icosahedron

3-simplex (tetrahedron)



24-cell -> D_4 lattice

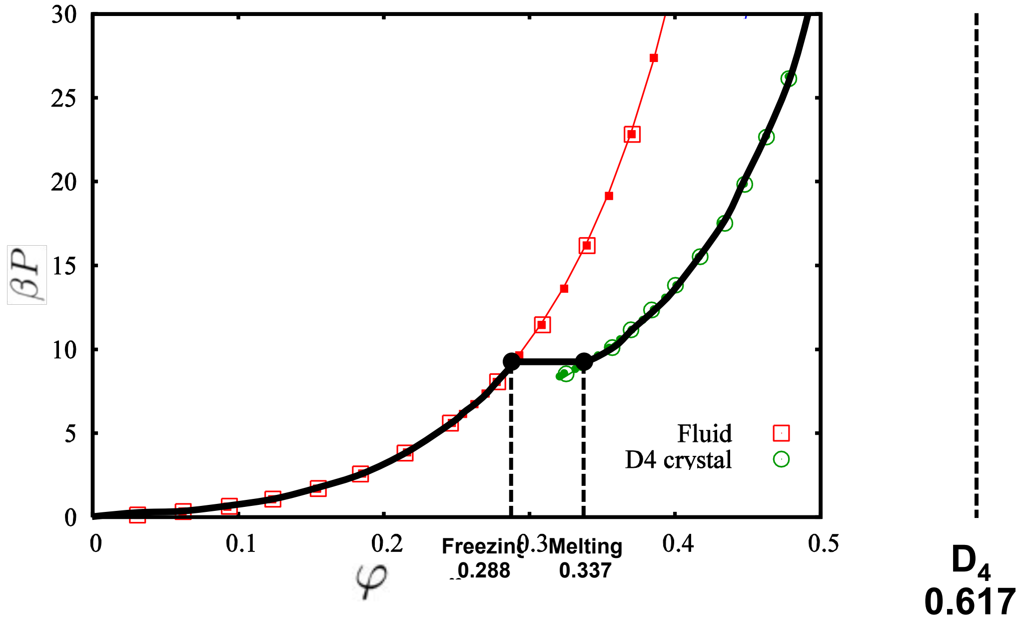
vs.



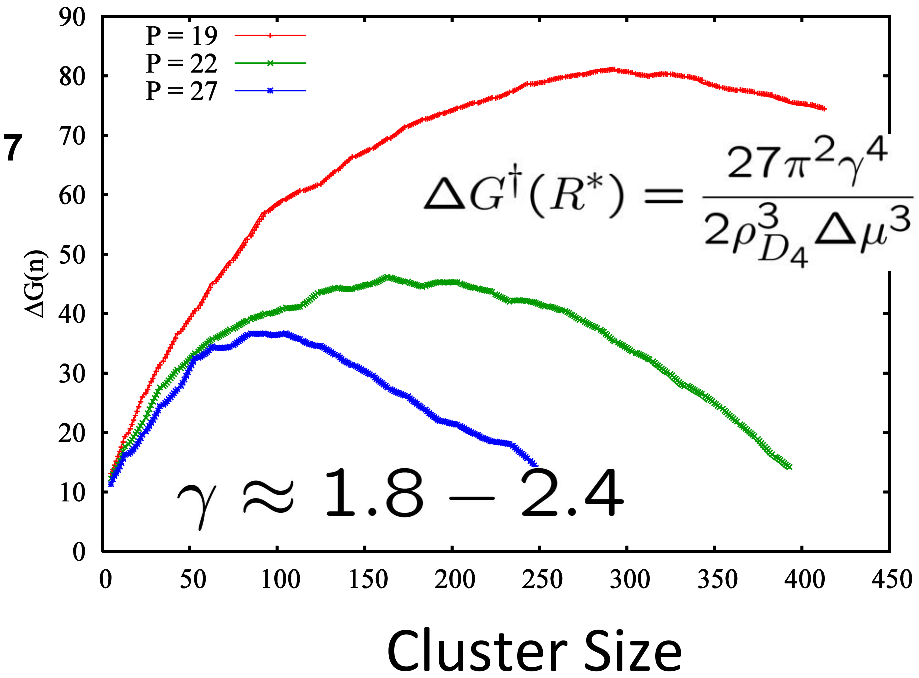
4-simplex

Pfender and Ziegler, Notices AMS (2004)

4D nucleation barrier



4D surface free energy is 2-3 times **larger** than 3D at similar supersaturations!

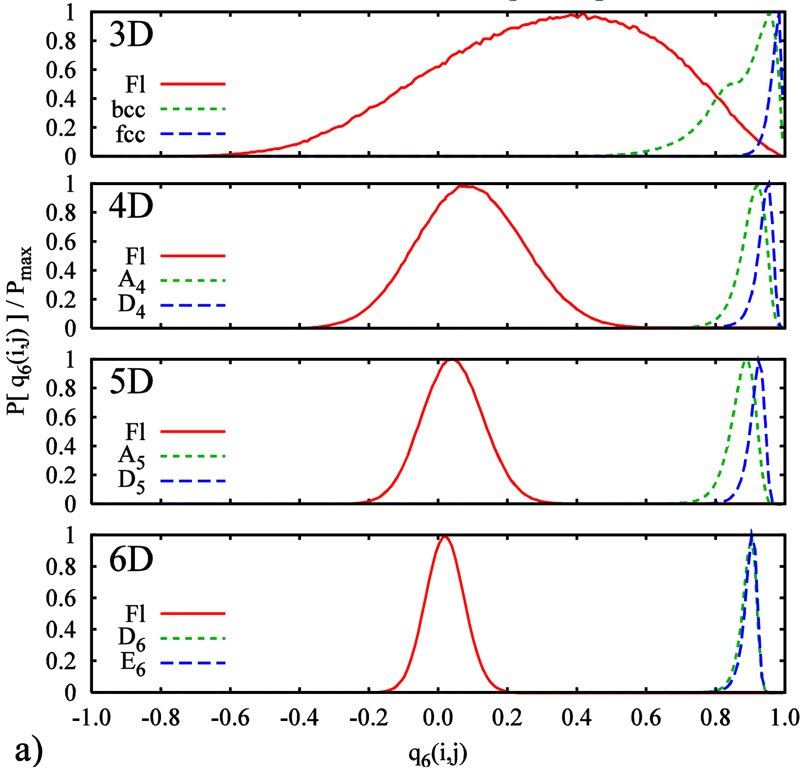


van Meel, Frenkel, Charbonneau, PRE (2009)

Liquid order and dimension

Bond order parameters
à la Steinhardt and Nelson

$$\mathbf{q}_k(i)\cdot\mathbf{q}_k(j)=\frac{1}{N(i)N(j)}\sum_{p=1}^{N(i)}\sum_{q=1}^{N(j)}G_k^1(\hat{\mathbf{r}}_{pi}.\hat{\mathbf{r}}_{qj})$$



- Liquid/crystal structure resemblance vanishes with dimension.
- In high-dimensions, glasses are more easily accessible than crystal.

van Meel, Charbonneau, Fortini, Charbonneau, PRE (2009)

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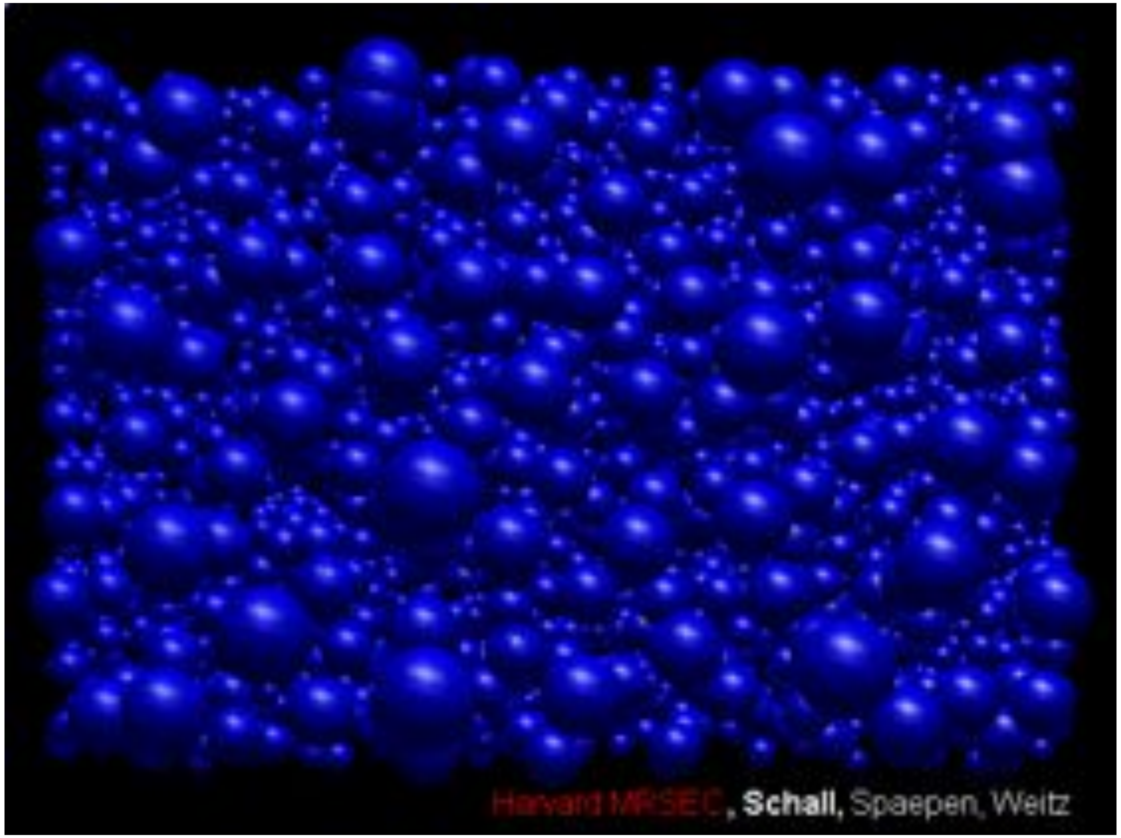
The New York Times

The Nature of Glass Remains Anything but Clear

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS | OPINION

David A. Weitz, a physics professor at Harvard, joked, "There are more theories of the glass transition than there are theorists who propose them." Dr. Weitz performs experiments using tiny particles suspended in liquids to mimic the behavior of glass, and he ducks out of the theoretical battles. "It just can get so controversial and so many loud arguments, and I don't want to get involved with that myself."



"[T]here were almost as many versions of the phlogiston theory as there were pneumatic chemists. That proliferation of versions of a theory is a very usual symptom of crisis."

-- Kuhn, *The Structure of Scientific Revolutions* (1962)

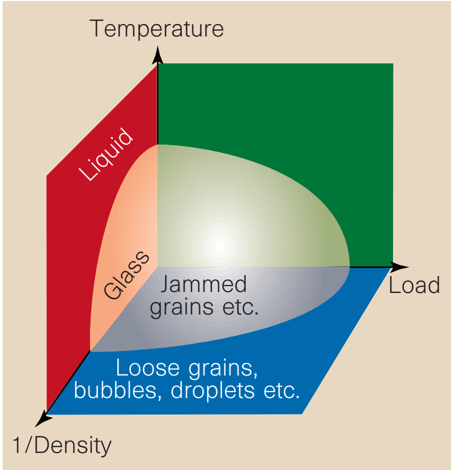
K. Chang, NYT, 29/07/2008

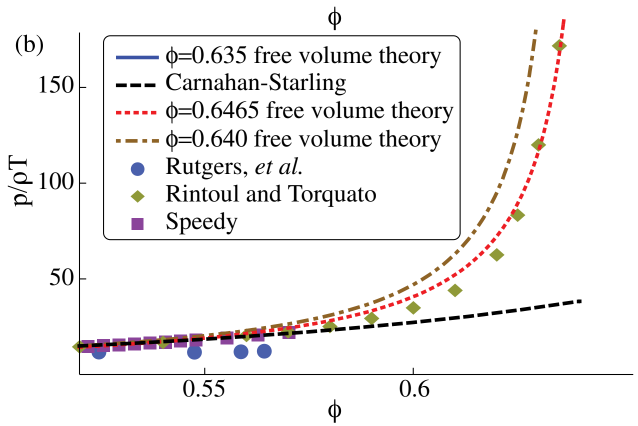
Hard sphere jamming

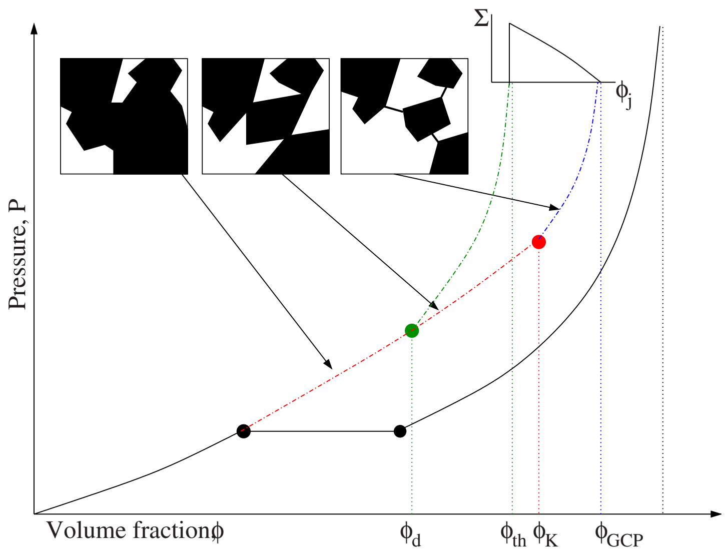
Out-of-equilibrium critical transition, hence describing it requires a good microscopic glass theory.

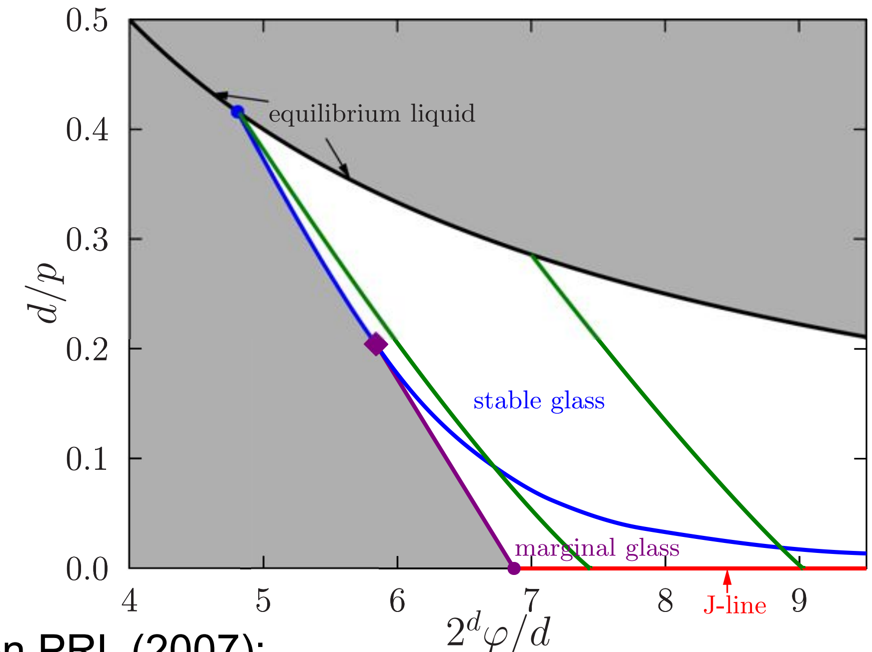
->Stringent test of glass theories.

Jamming phase diagram (hindsight is 20/20)



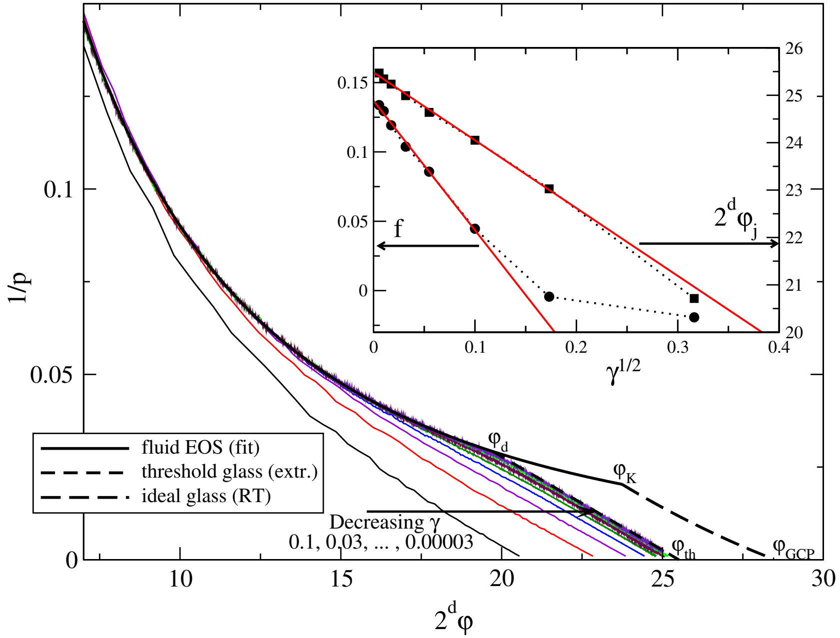




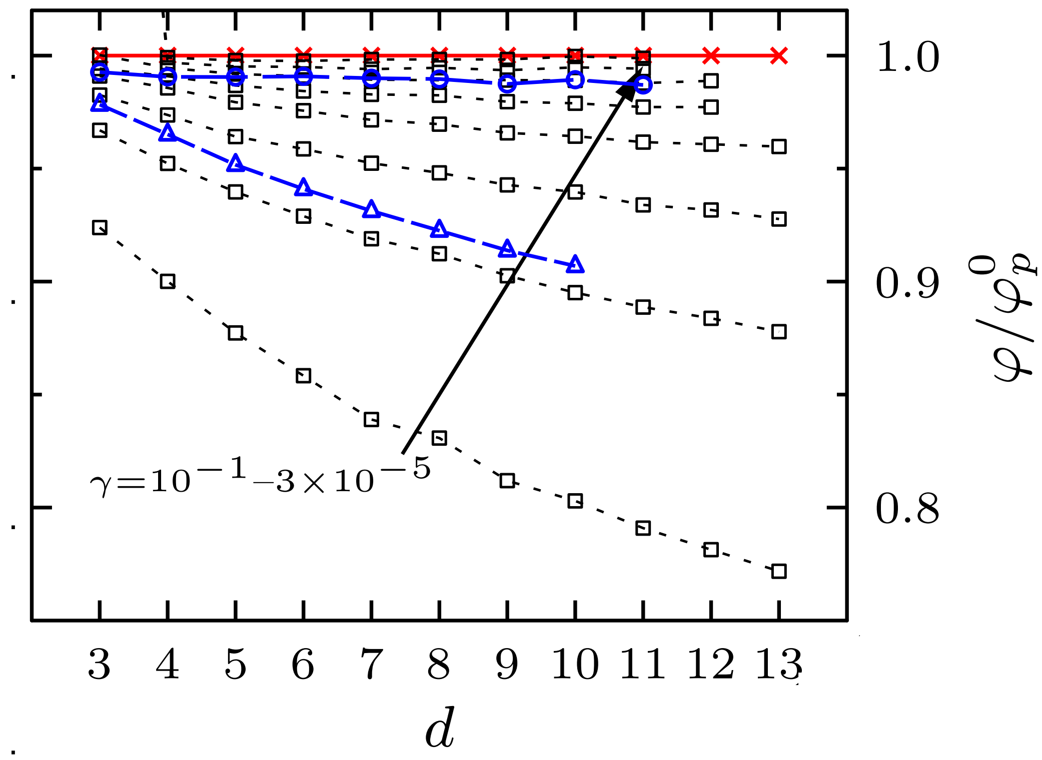


Liu and Nagel Nature (1998), Liu and Kamien PRL (2007);
PZ RMP (2010); CKUPZ Nat. Comm. (2014)

Evolving Density

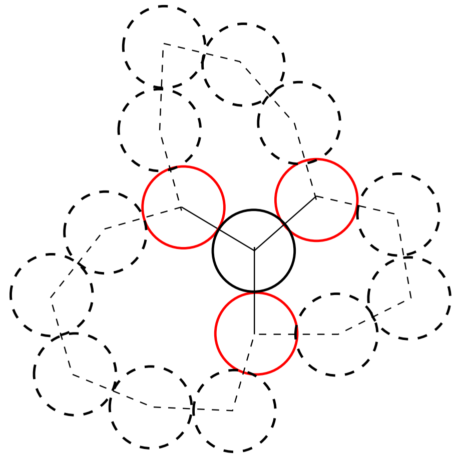


Consistent with *d*=3 results
Chaudhuri, Berthier, Sastry PRL (2010)



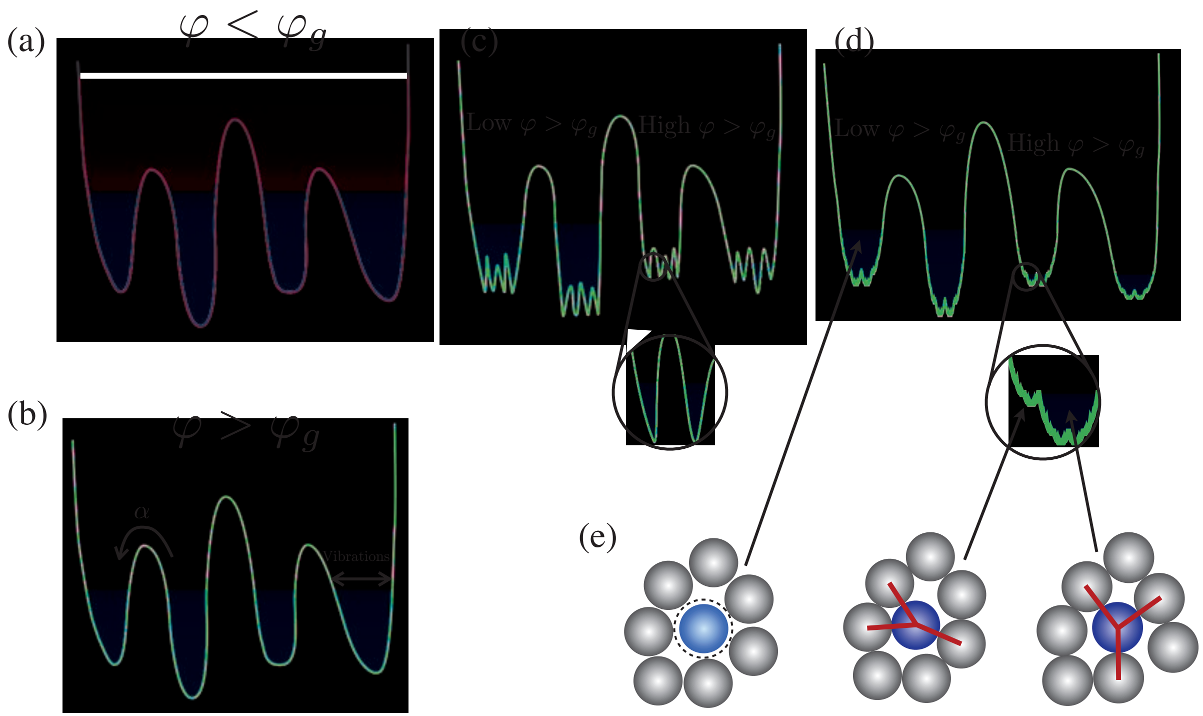
CIPZ PRL (2011); CCPZ PRL (2012)

Cage Collapse



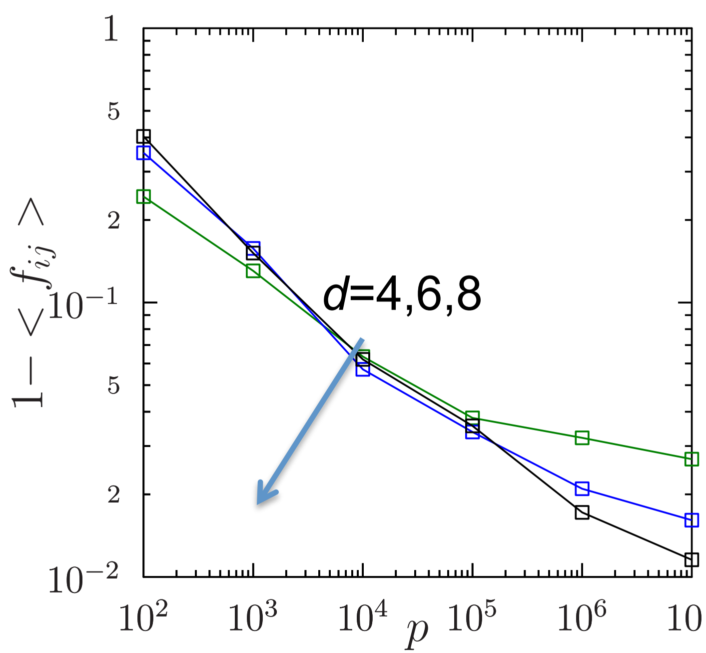
Between the liquid and jamming, something must happen, because

$$\bar{z} = 2d \text{ (isostaticity)}$$
$$\bar{z} \sim e^d \text{ (liquid shell)}$$



CKUPZ Nature Comm. (2014)

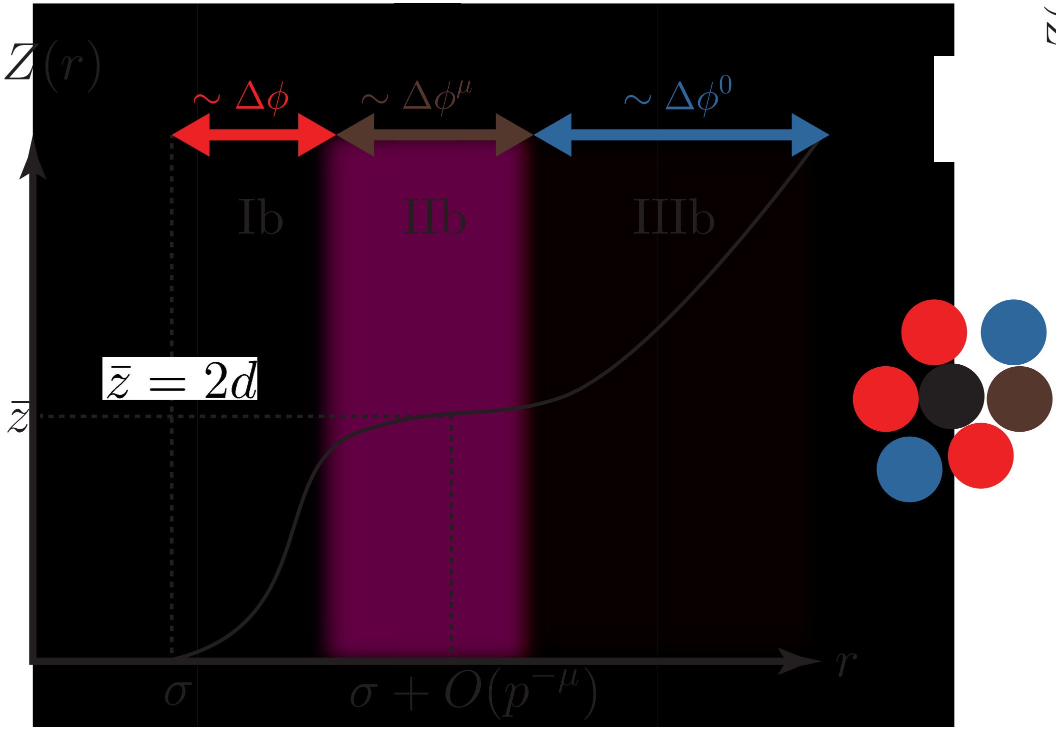
How determined are the force contacts (and the rattlers)?

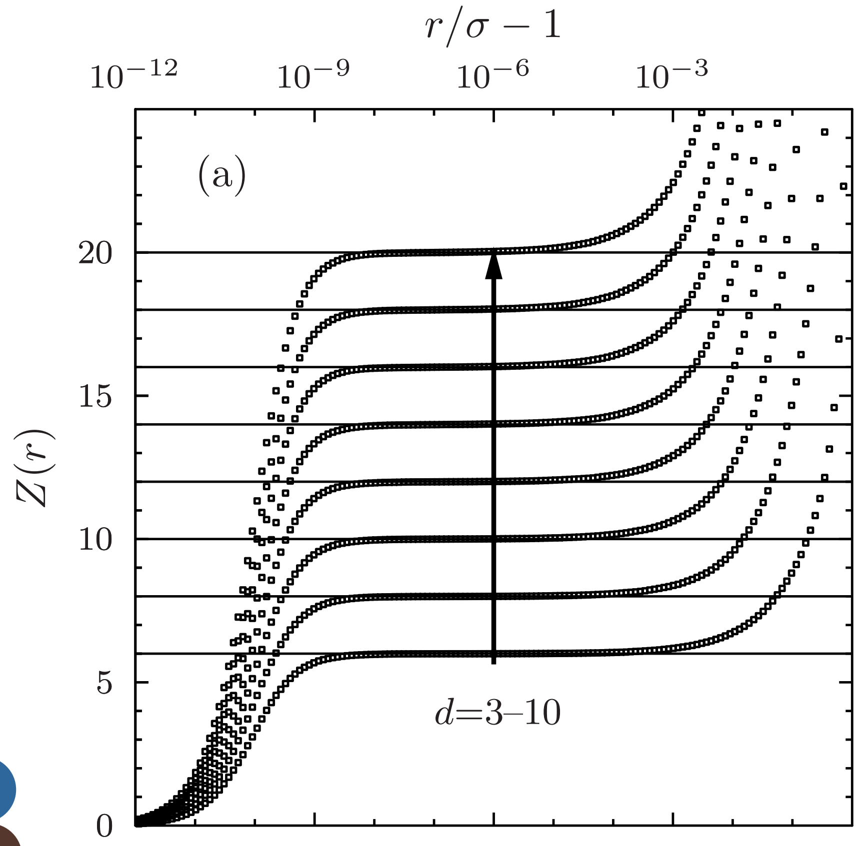


Jamming (marginally stable) cage

As proposed by Wyart PRL (2012), two critical regimes can be identified.

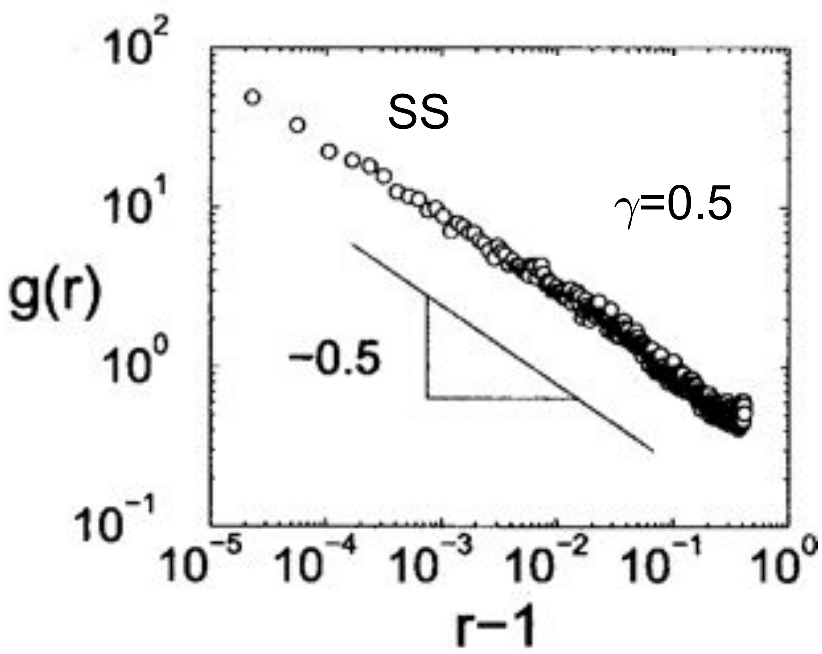
1RSB solution does not: critical exponents are 0.



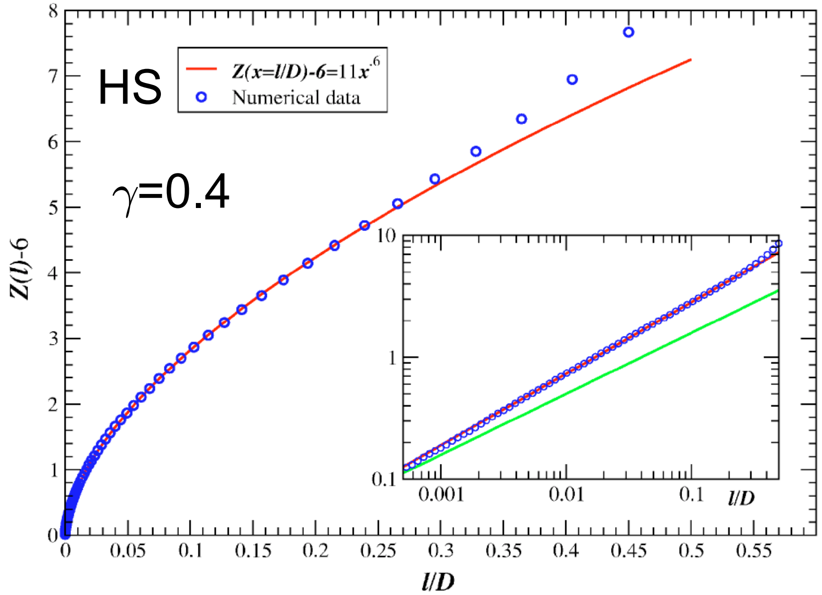


CCPZ PRL (2012)

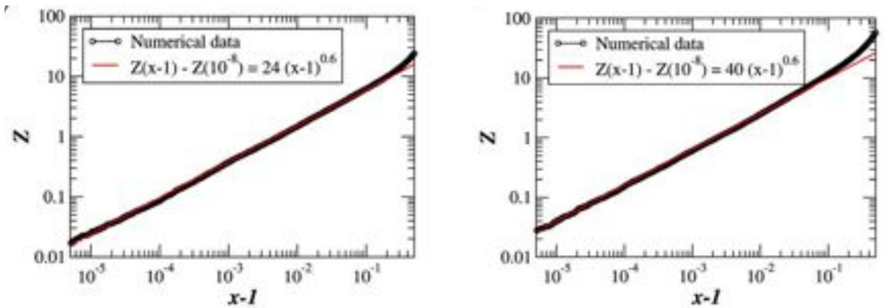
1st power law: near contacts



Silbert, Liu, Nagel, PRE (2005)

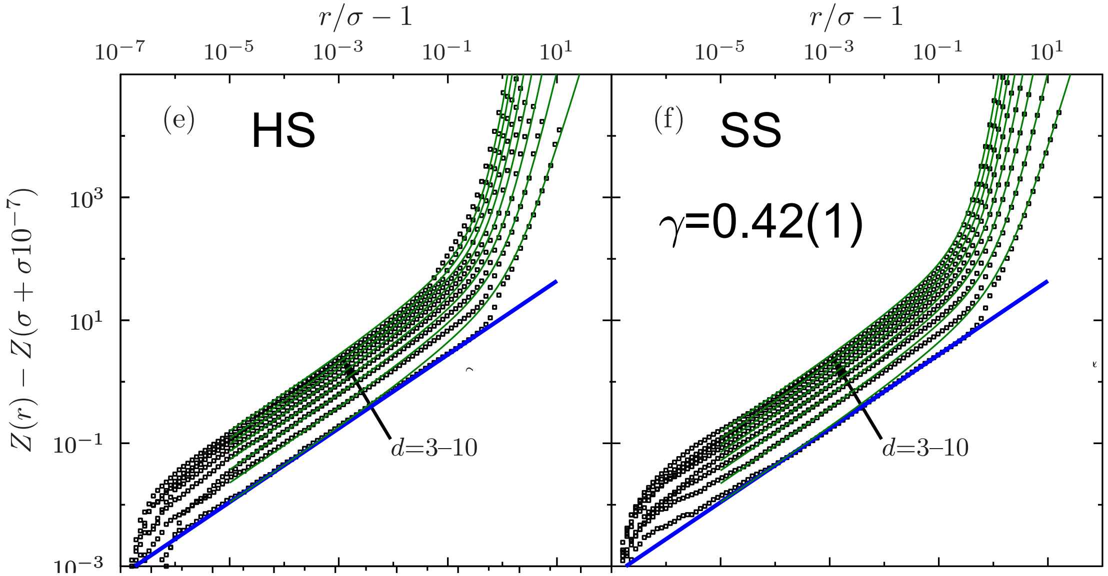


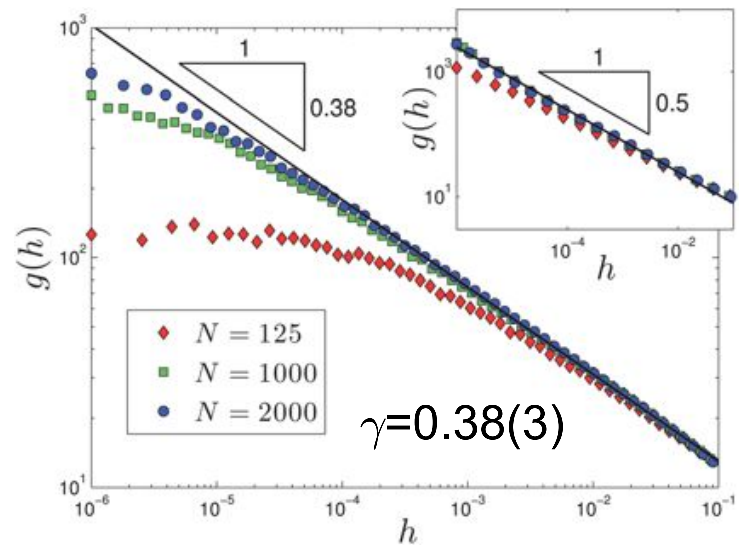
Donev, Stillinger, Torquato, PRE (2005)

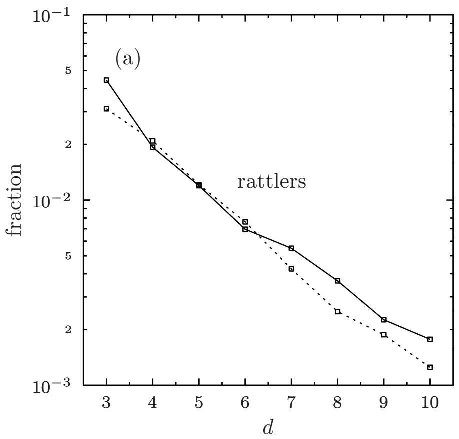


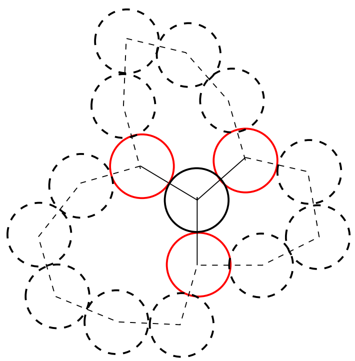
Skoge et al., PRE (2006)

Near contacts: remove rattlers









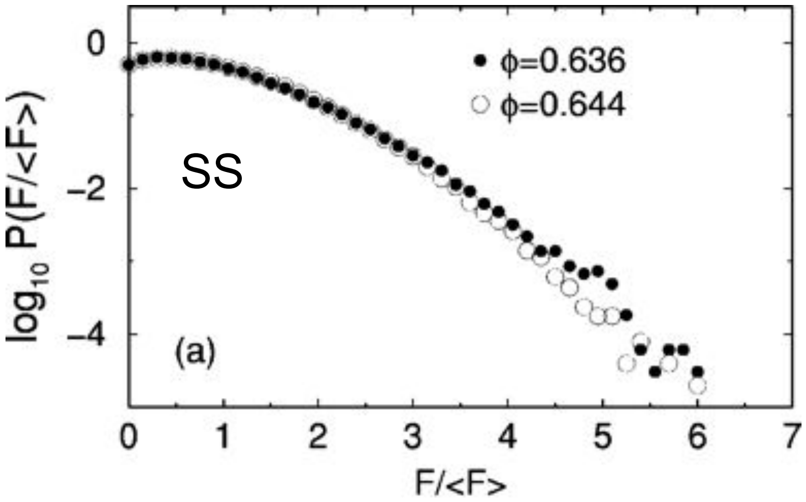
FullRSB γ=0.41269

Suggest that upper *and* lower critical dimension *d*=2 (?)

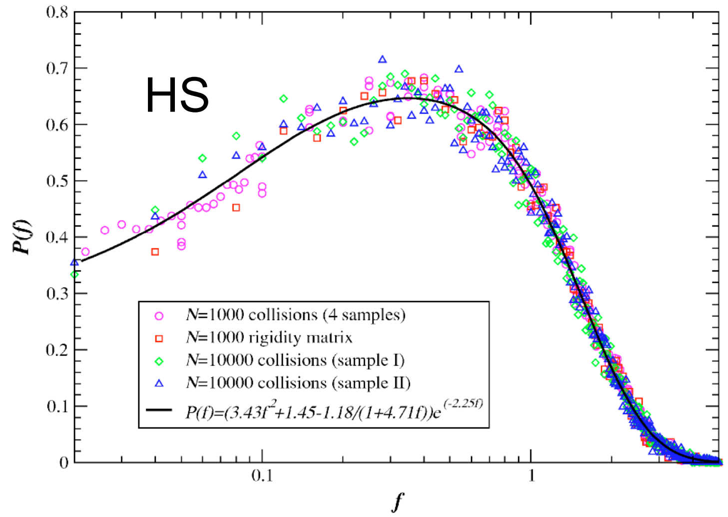
Agrees with finite-size scaling arguments of Goodrich and Liu PRL (2012).

CCPZ PRL (2012); Lerner, Duering, Wyart Soft Matter (2013)

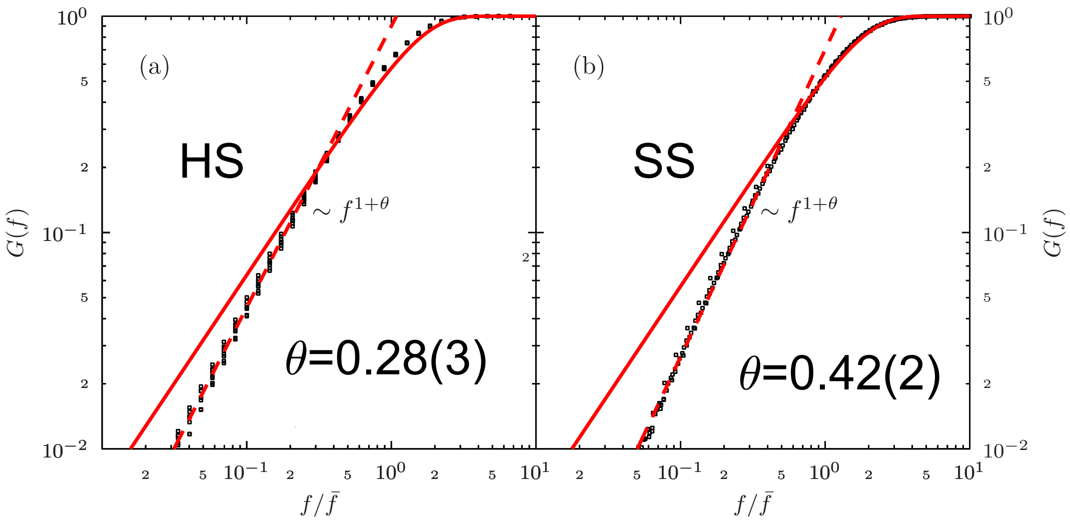
2^{nd} power law: force contacts



O'Hern et al. PRE (2003)



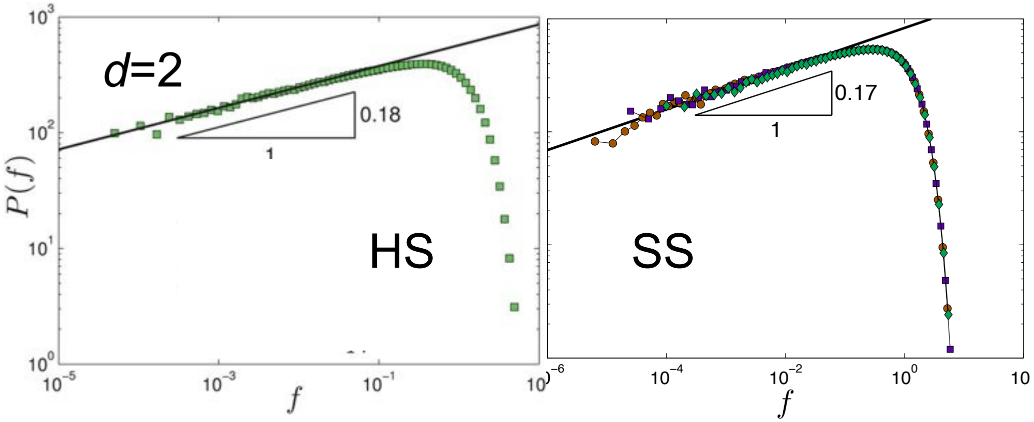
Donev, Stillinger, Torquato, PRE (2005)



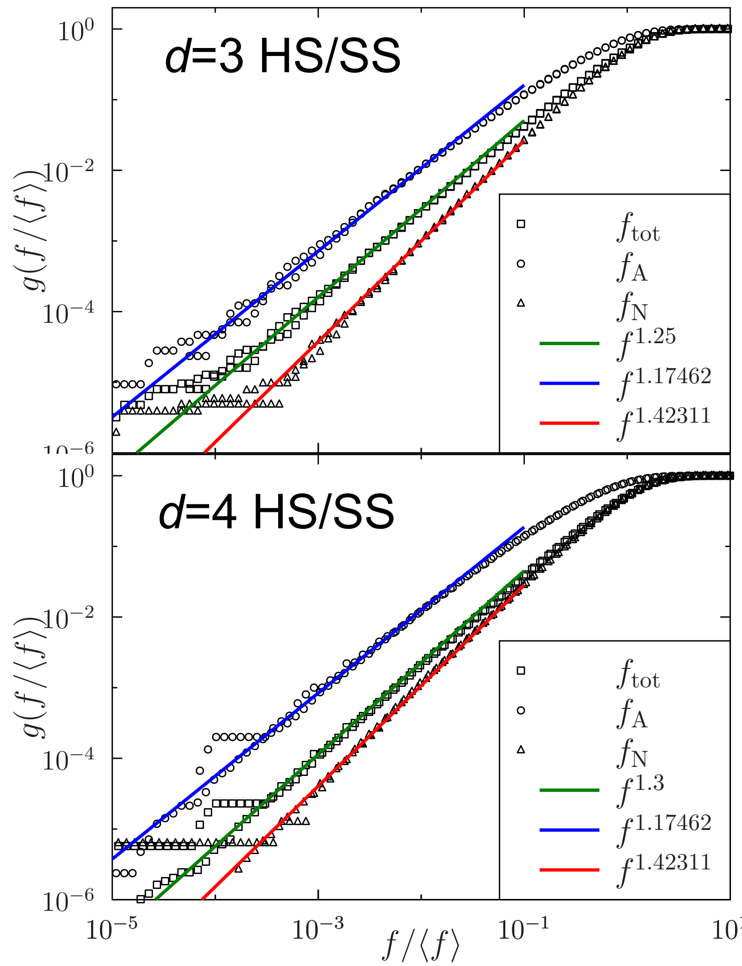
CCPZ PRL (2012)

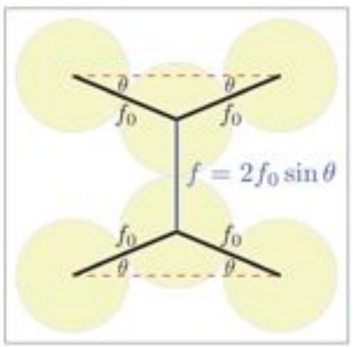
Embarrasingly different…

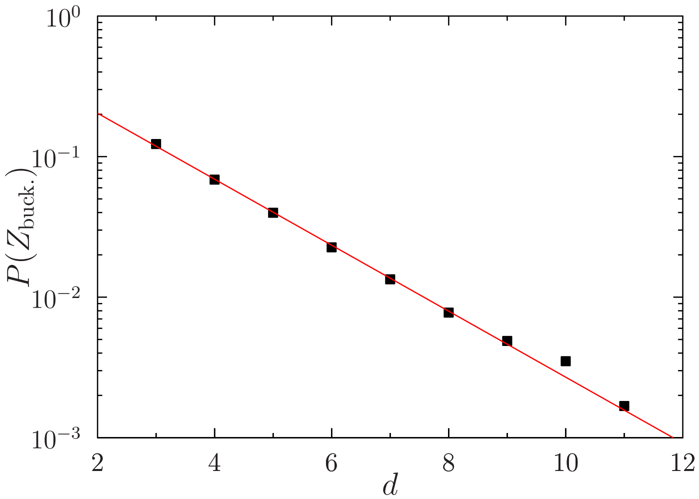
Force contacts: remove bucklers



Lerner, Duering, Wyart Soft Matter (2013); DeGiuli et al. arXiv:1402.3834

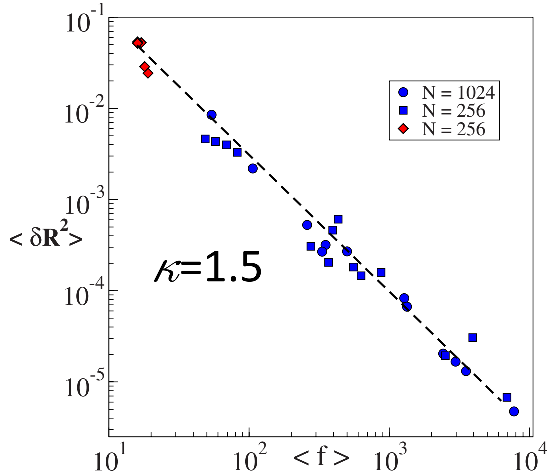




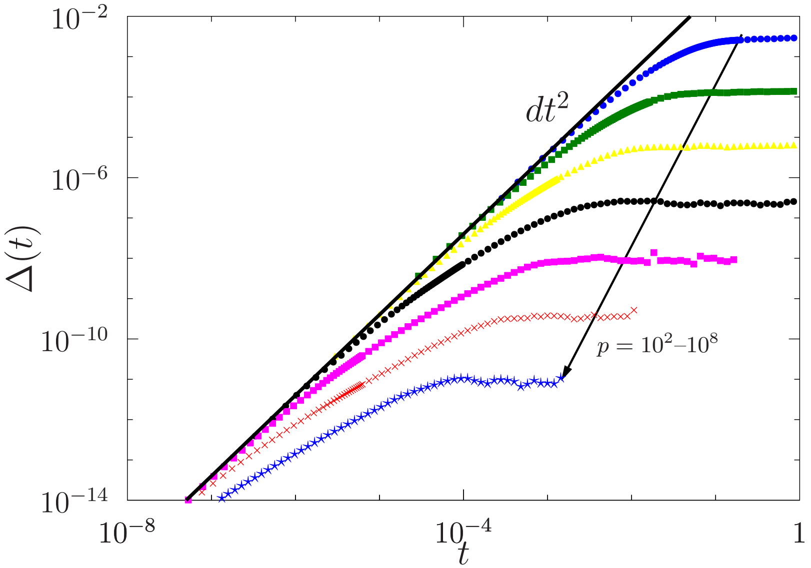


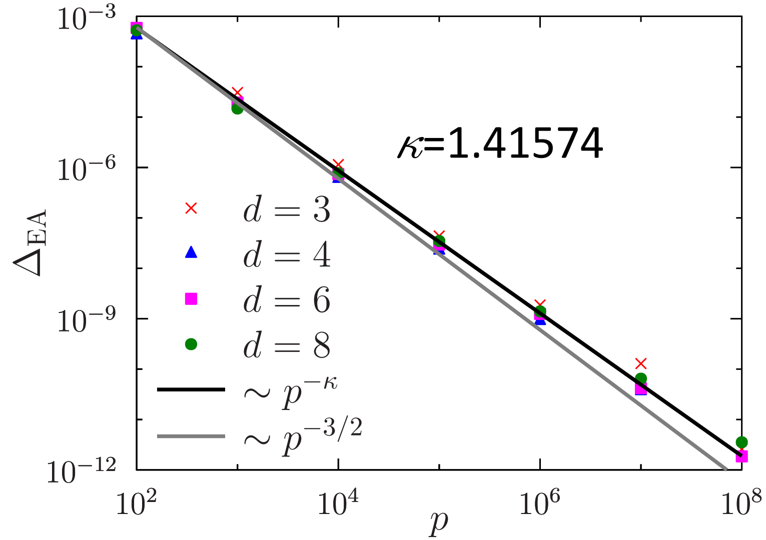
CCPZ unpublished (2014)

Cage evolution



Brito and Wyart J. Chem. Phys. (2009)





High pressure challenges:
-eliminate rattlers
-network and thus rattlers reorganize

CKUPZ Nat. Comm. (2014)

Conclusions

- Some qualitative *and quantitative* features of the mean-field full RSB solution persist all the way down to *d*=2.
- Refinement and measurement of critical exponents and of deviations is ongoing.
- Some aspects of the Gardner transition may be experimentally testable.
- Plenty of work about the dynamical transition has also been done -> see Yuliang Jin's poster.