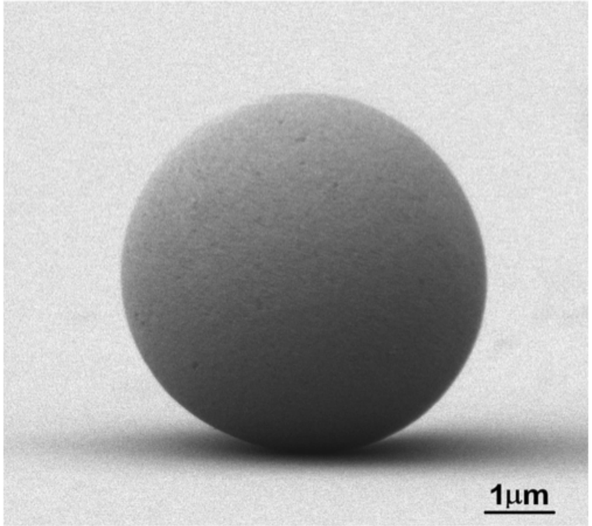

(Towards)
A dynamic contact model for adhesive micron-sized spheres

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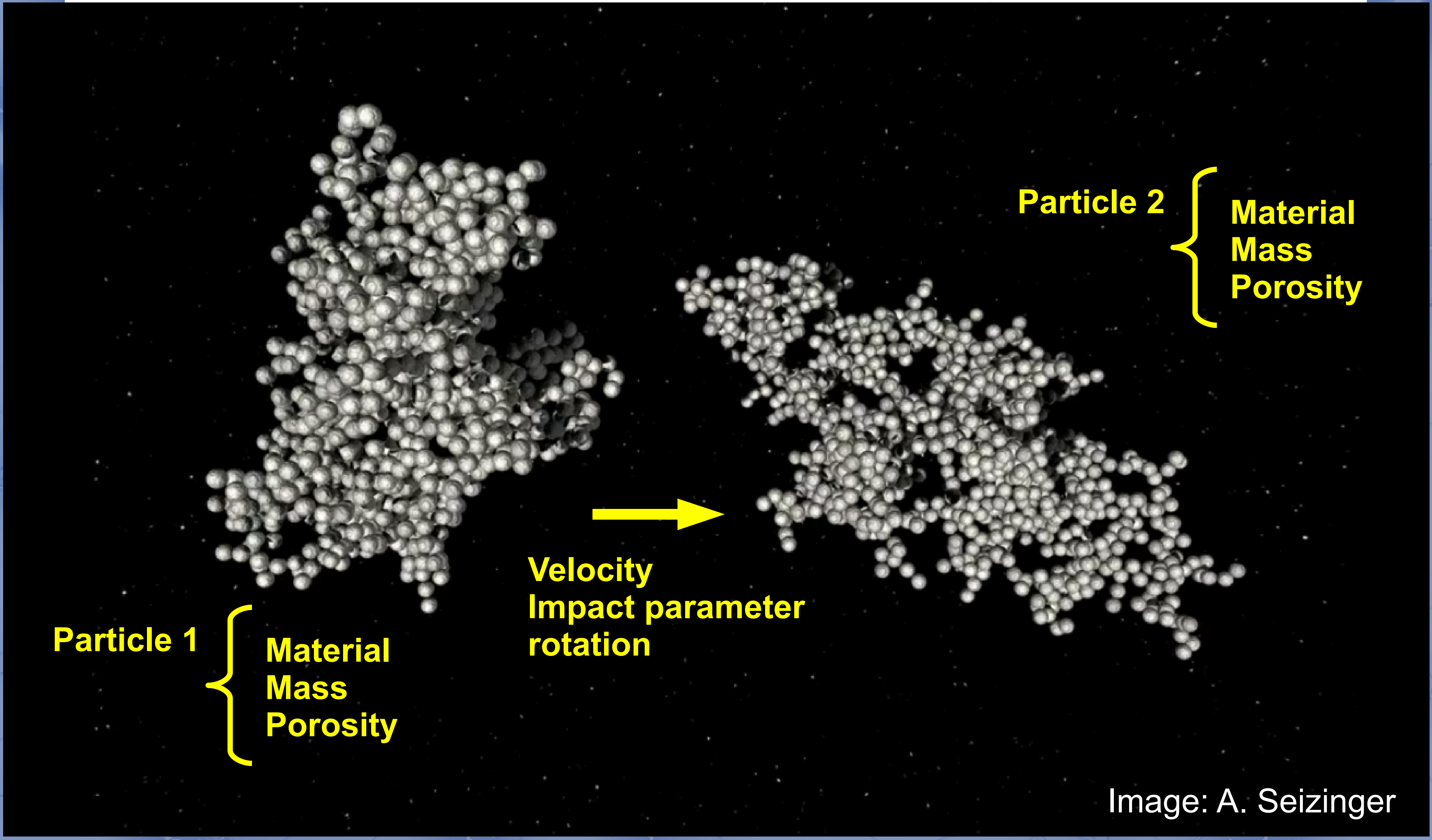
with AGGM Tielens, Carsten Dominik,
Carsten Guettler, Daniel Heisselmann

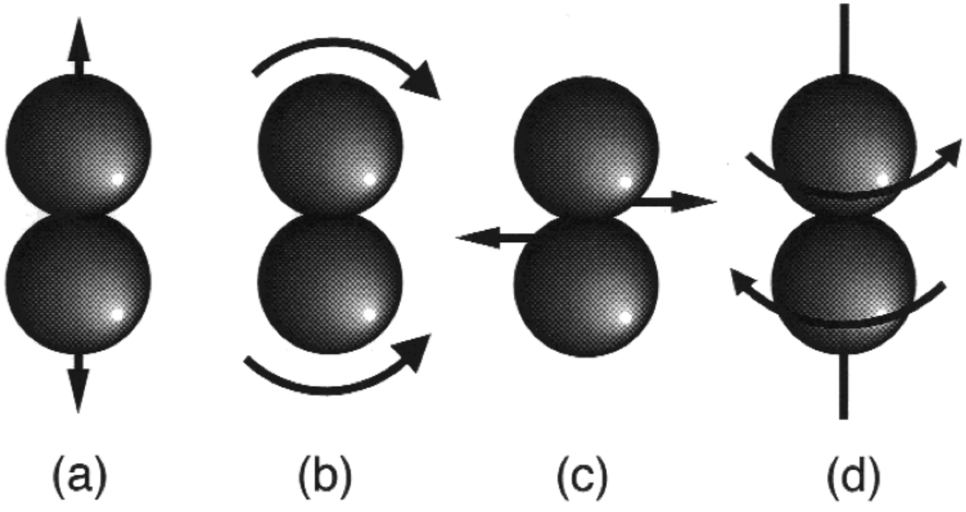
Planet formation and Evolution – Munich 4 sept 2012

Problem


Particle 2
Material
Mass
Porosity
Velocity
Impact parameter
rotation
Particle 1
Material
Mass
Porosity
Image: A. Seizinger

Molecular Dynamics-like approach

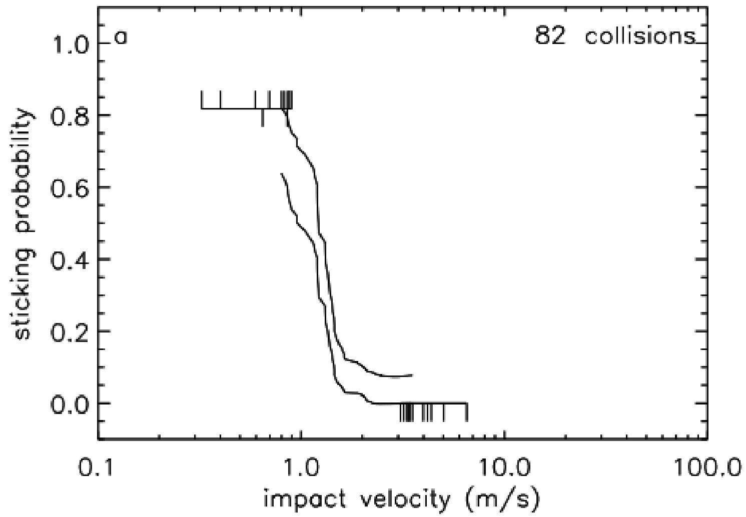
- Model dust grains as collection of spherical micron-sized ***monomers***, held together by (attractive) surface forces
- Force laws governing *radial motion* (a), *rolling* (b), *sliding* (c), and *spinning* (d) of monomers derived by Dominik & Tielens (1995,1996,1997)



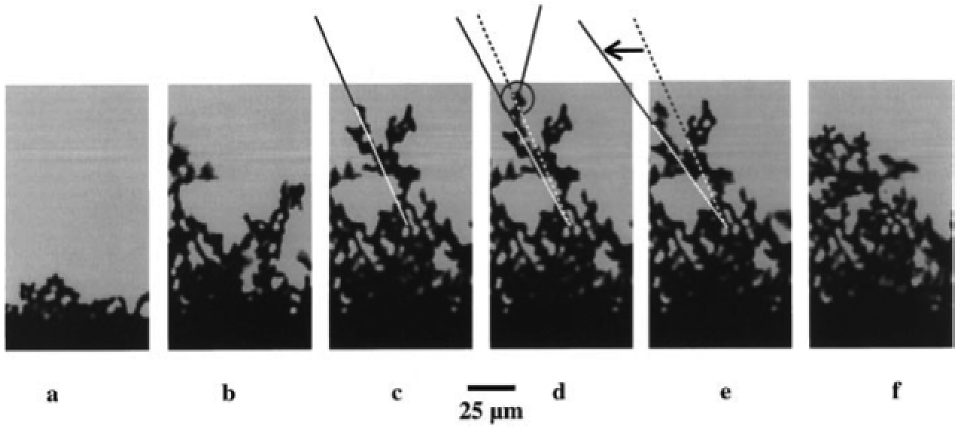
- Force laws based on quasi-static Johnson-Kendall-Roberts (JKR) contact model, a theory that balances **elastic** and **surface** energy

Experiments in dynamic situations

- Experimentally determined sticking velocities for micron-sized SiO_2 particles too high by factor of ~10 (Poppe et al 2000)
- Larger rolling friction found in experiments (Heim et al 1999, Blum & Wurm 2000)
- Simulations of aggregates need stiffer force laws to match experimental compression curves (Seizinger et al 2012)



(Poppe et al 2000)



(Blum & Wurm 2000)

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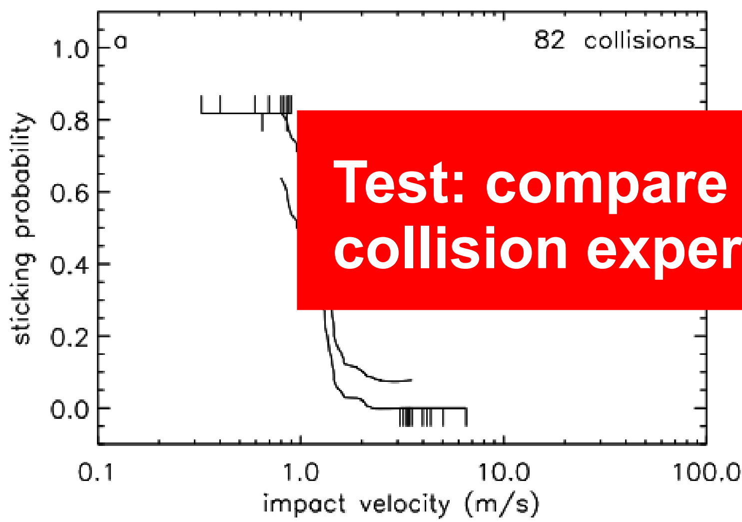
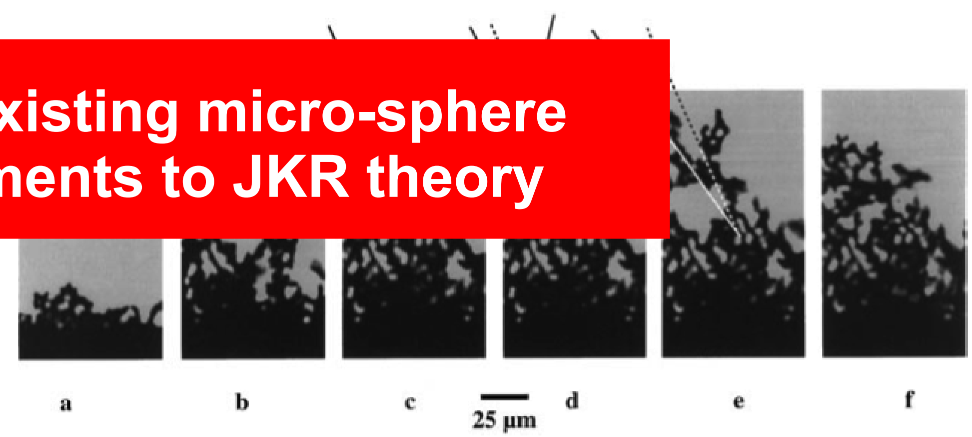


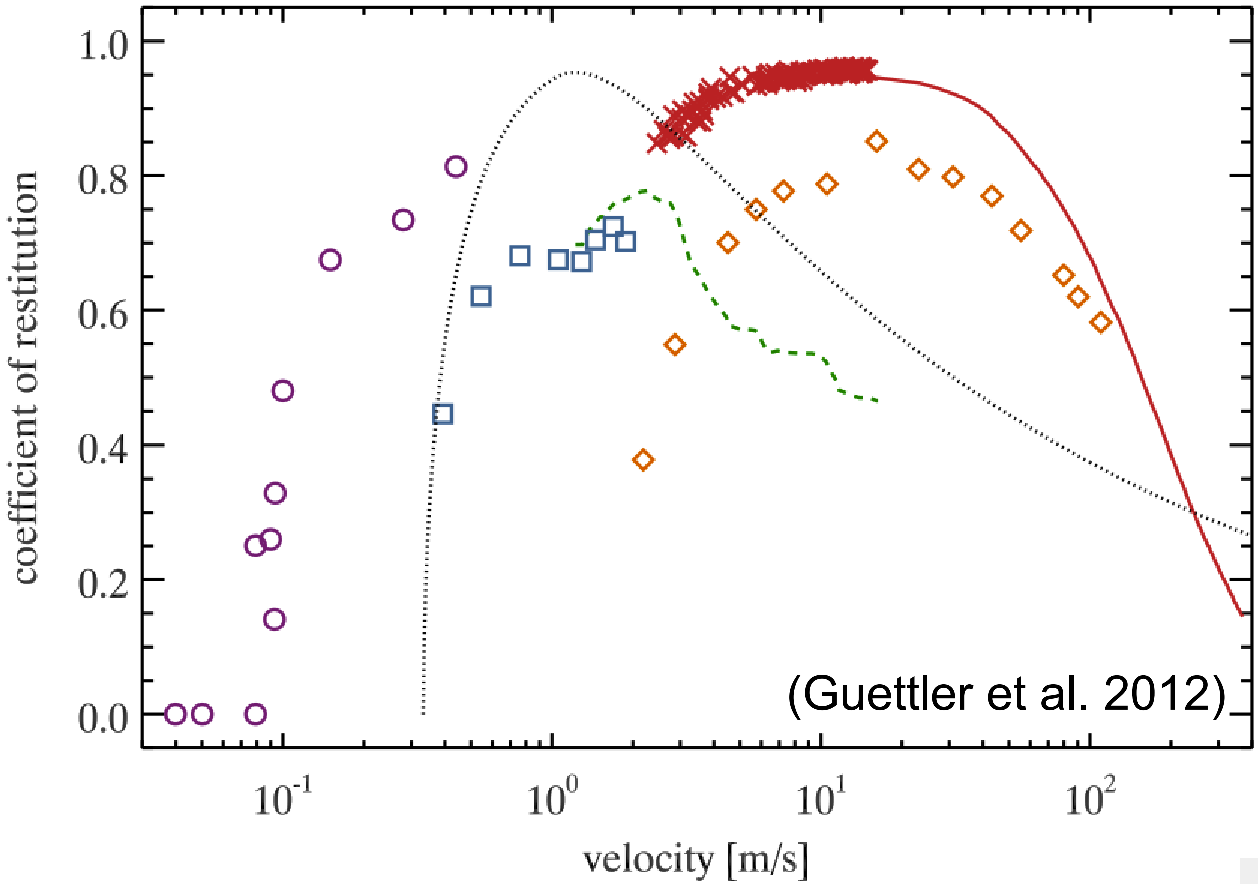
Test: compare existing micro-sphere collision experiments to JKR theory



(Poppe et al 2000)

(Blum & Wurm 2000)

Gathering collision experiments

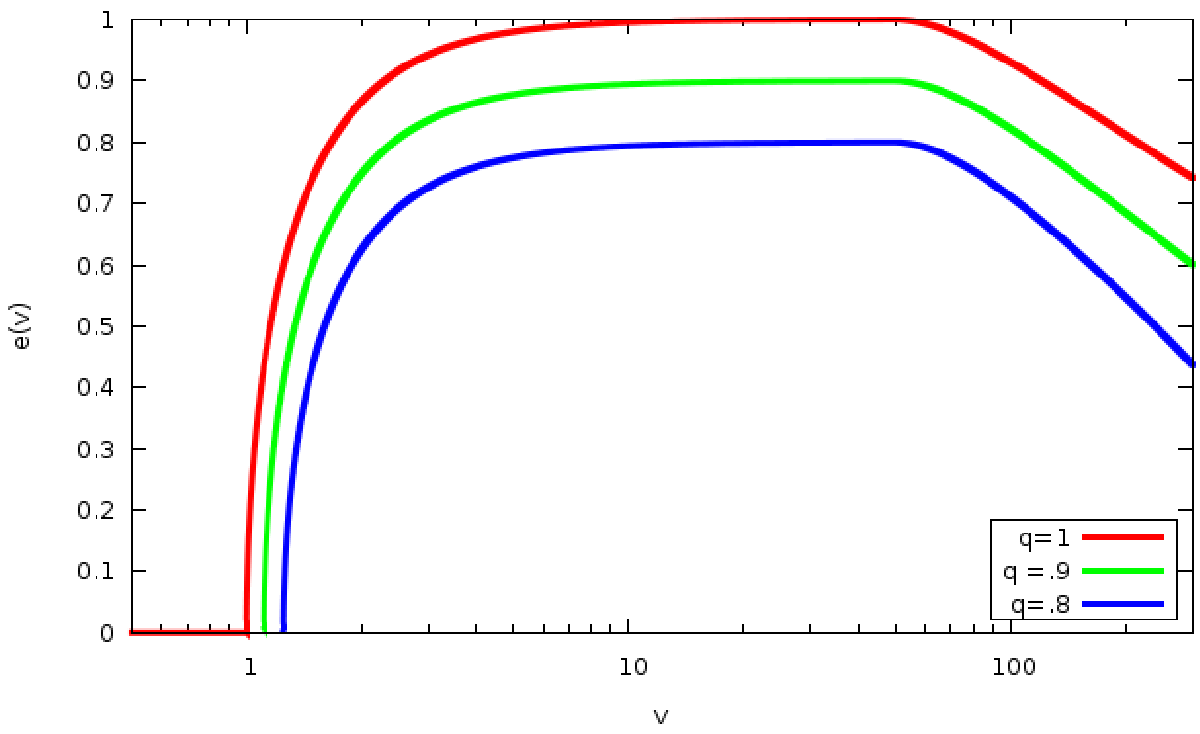


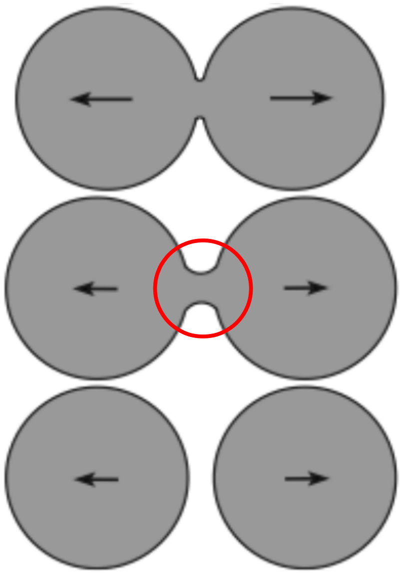
Materials include silicon, silica, metals, polymers...

- Study behavior of the *Coefficient of restitution* as a function of collision velocity

$$e \equiv -\frac{v_r}{v_i} = \sqrt{\frac{U_{K,r}}{U_{K,i}}}$$

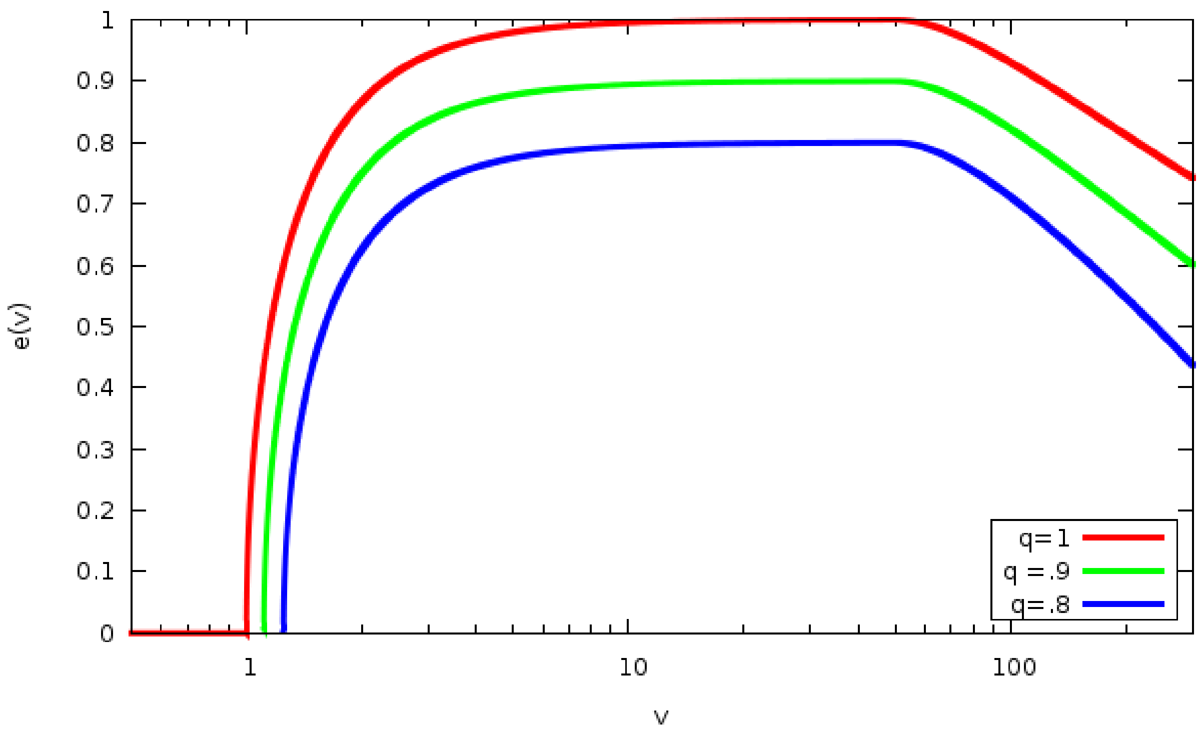
Analytical model

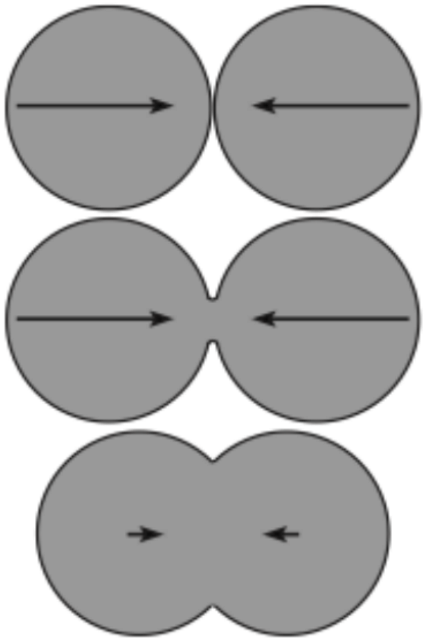




- At low velocities, the surface energy causes the collision to be inelastic, and result in sticking at some point (Johnson 1971+1985, Chokshi 1993)
- Fitting the ***sticking velocity*** gives the ***surface energy***

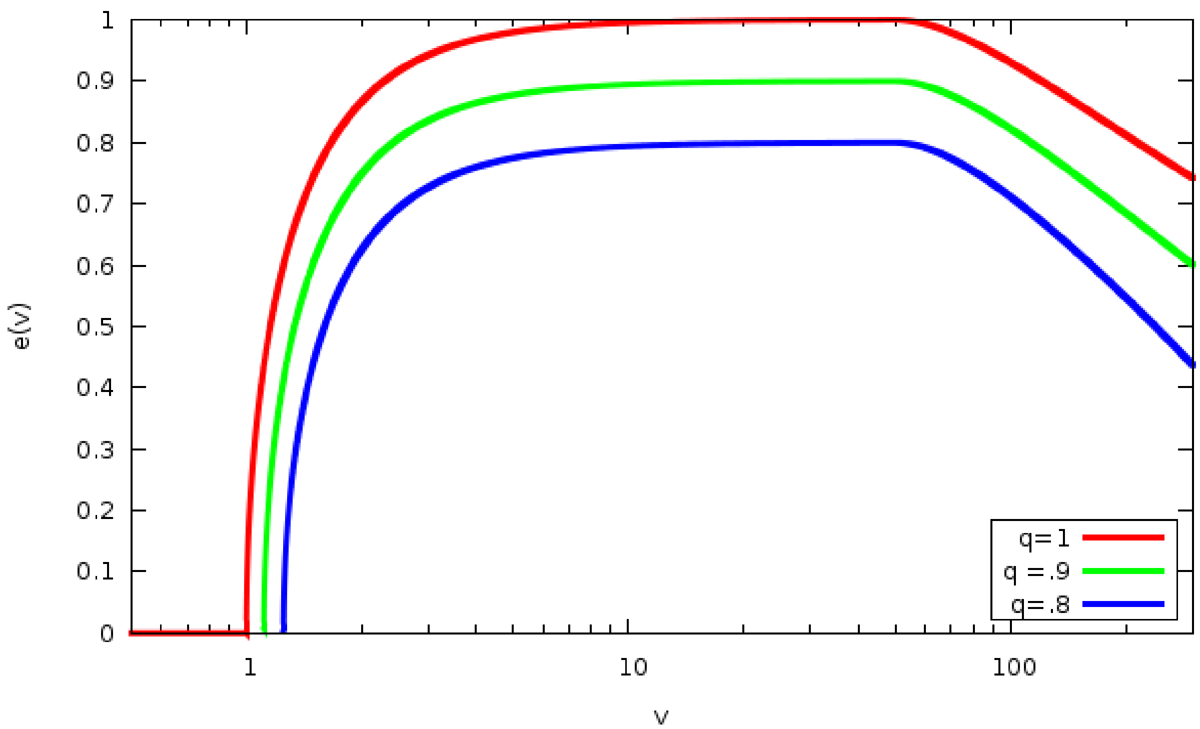
Analytical model





- At high velocities, the large pressure at the interface causes the spheres to plastically deform (Johnson 1985, Thornton & Ning 1998)
- Fitting the ***yield velocity*** gives the ***material strength***

Analytical model

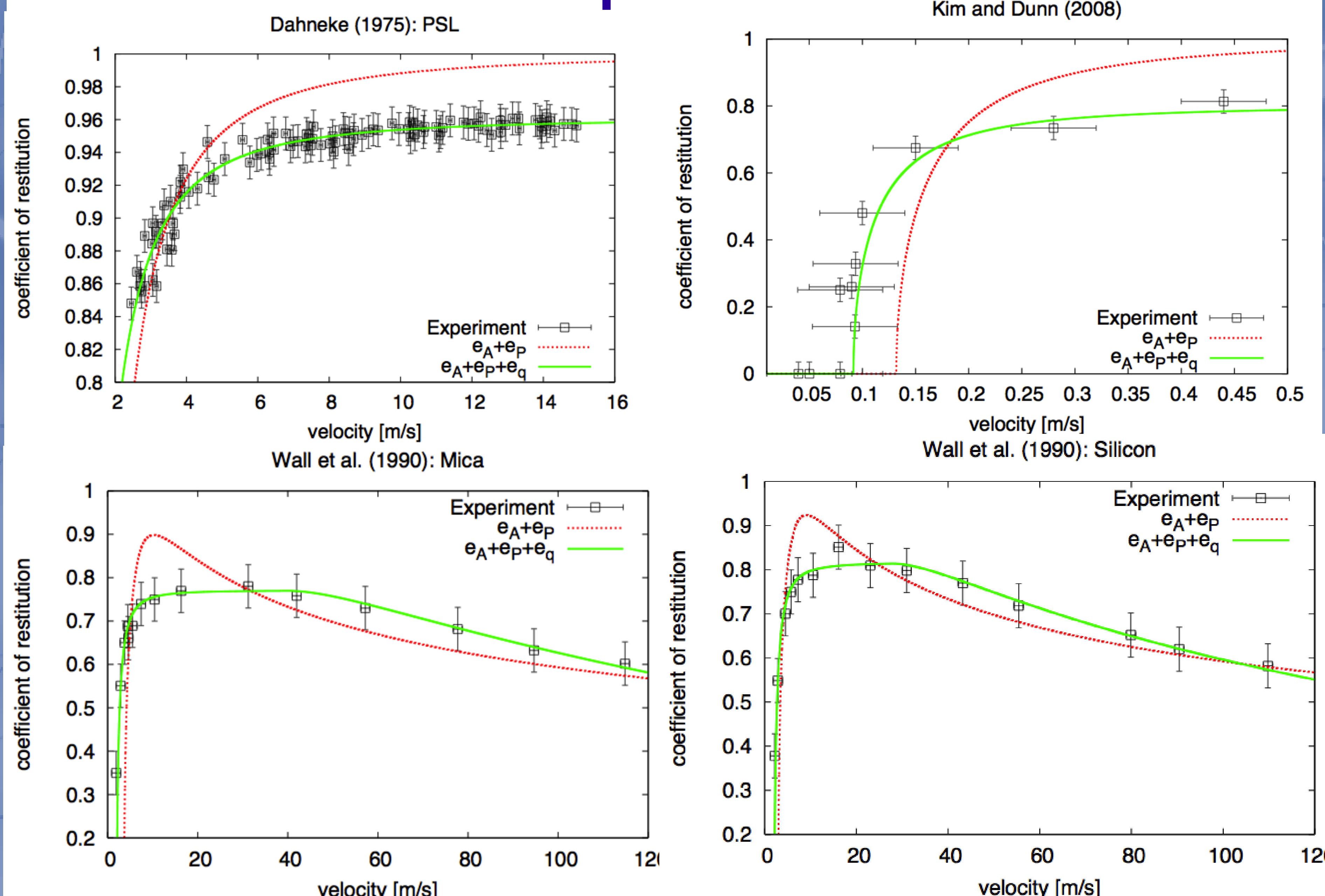


?

- At intermediate velocities, we see that majority of experiments are still inelastic. Cause of this dissipation unknown.
- For now, describe this with additional fitting parameter ***q***

Examples of fits

(Krijt et al. in prep)



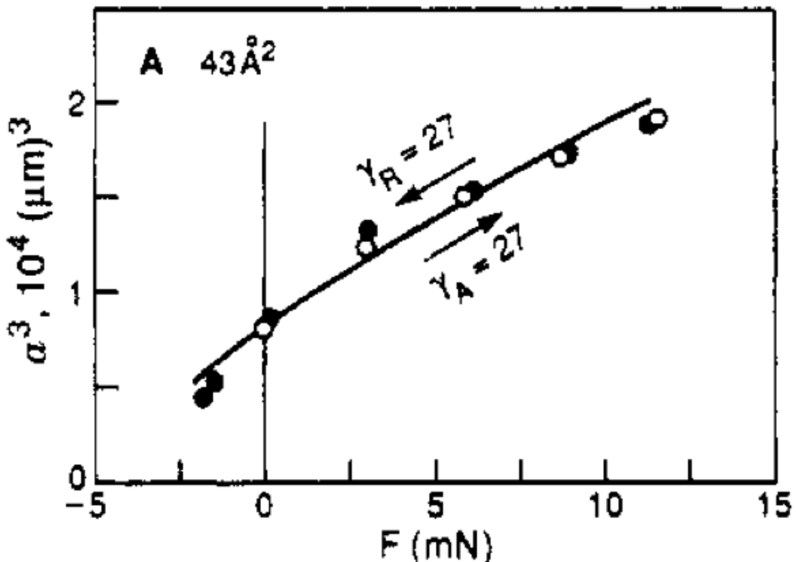
Results

- Relatively simple model fits experiments ranging in velocity, size, material, set-up, etc remarkably well
- Model describes 3 regimes:
    - *High velocities*: Outcome dominated by plastic deformation. Derived values of material strength in agreement with theory
    - *Intermediate velocities*: collisions not perfectly elastic. Cause of ***q*** unknown, elastic waves ruled out
    - *Low velocities*: **Surface energies found are 2-20 larger than quasi-static values**
- **JKR theory alone *not* able to explain experimental collisions**

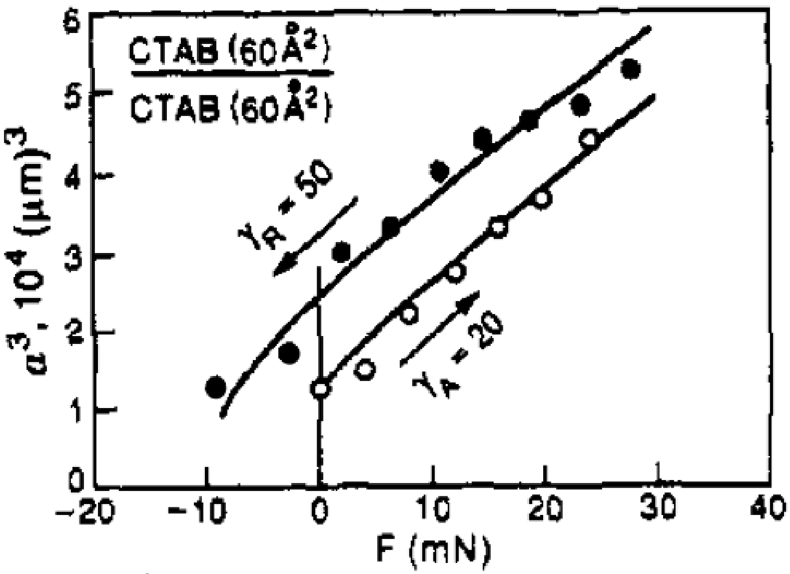
Concept for dynamical model: adhesion hysteresis

- In JKR, loading/unloading is reversible, and a unique relation exists between the size of the contact and the inter-particle force
- For polymer-like materials, so-called *adhesion hysteresis* is often observed, and can be described by using a variable *effective surface energy*

JKR – like



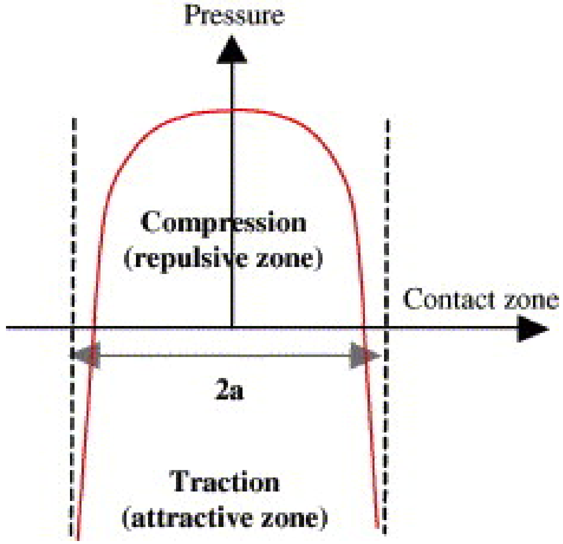
hysteretic

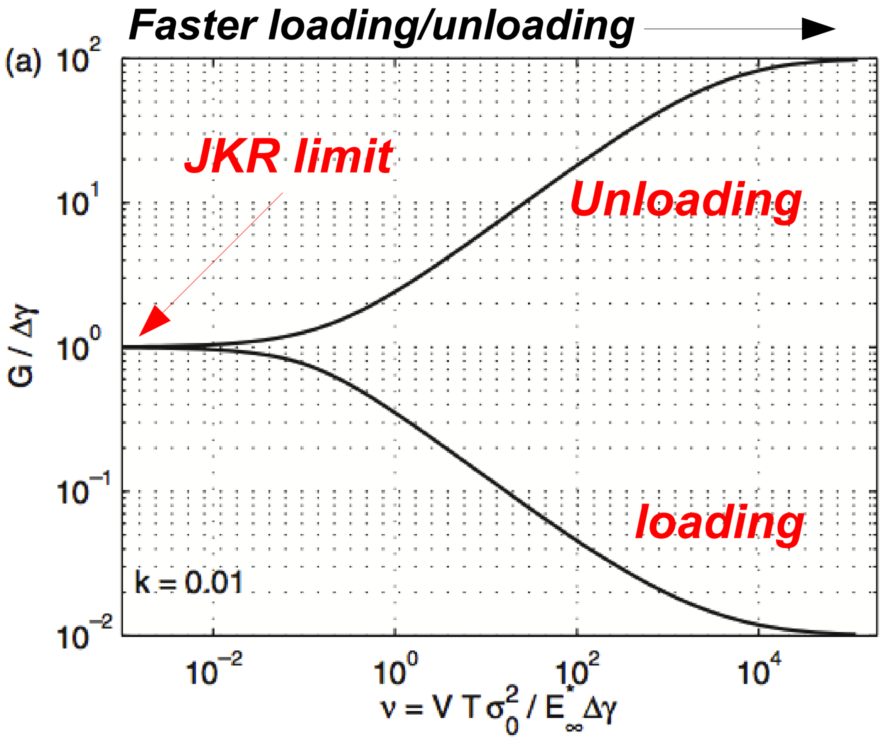


(Chen et al. 1991)

Concept for dynamical model: adhesion hysteresis

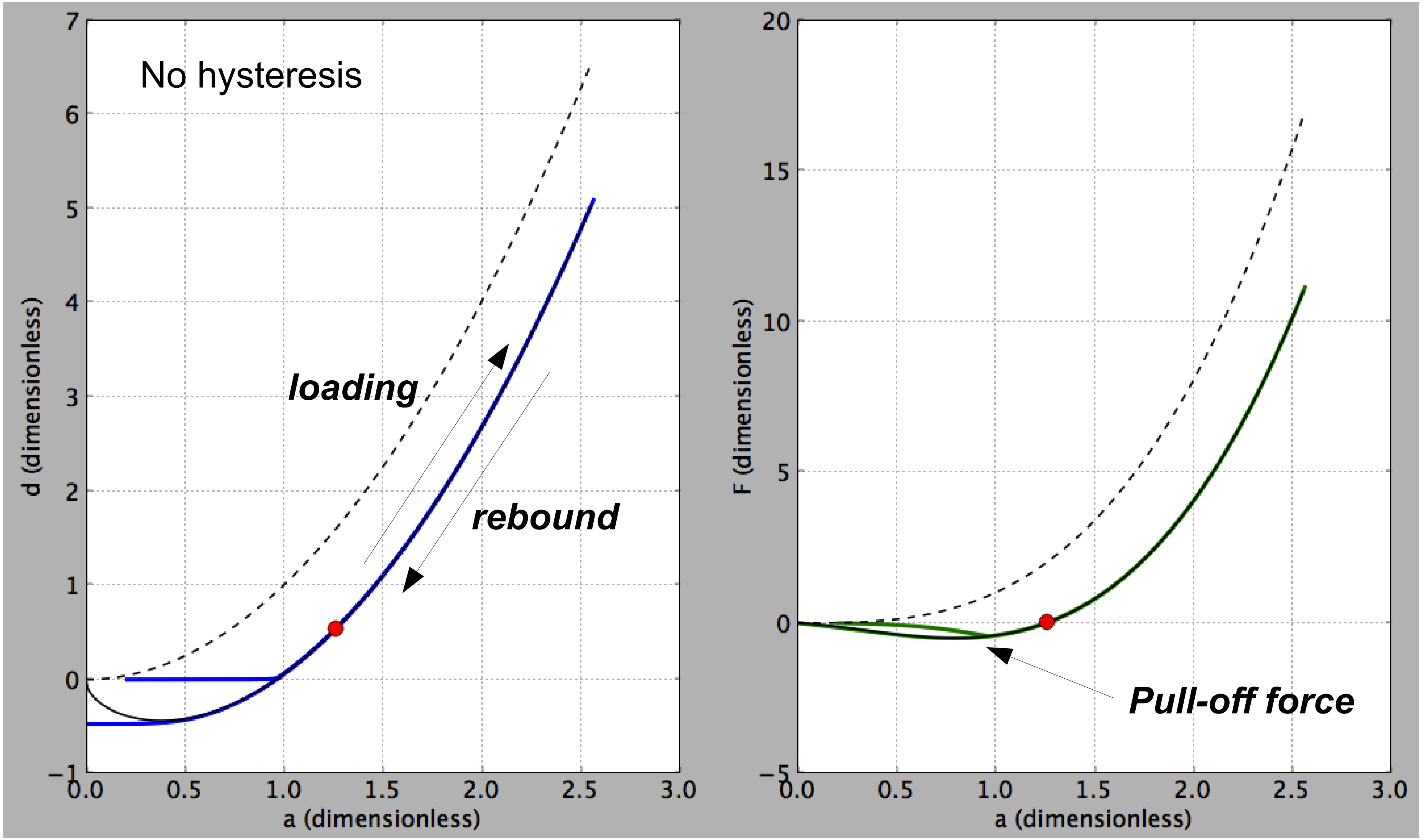
- Hysteresis often attributed to non-linear behavior near the contact edge, where tensile stresses are high



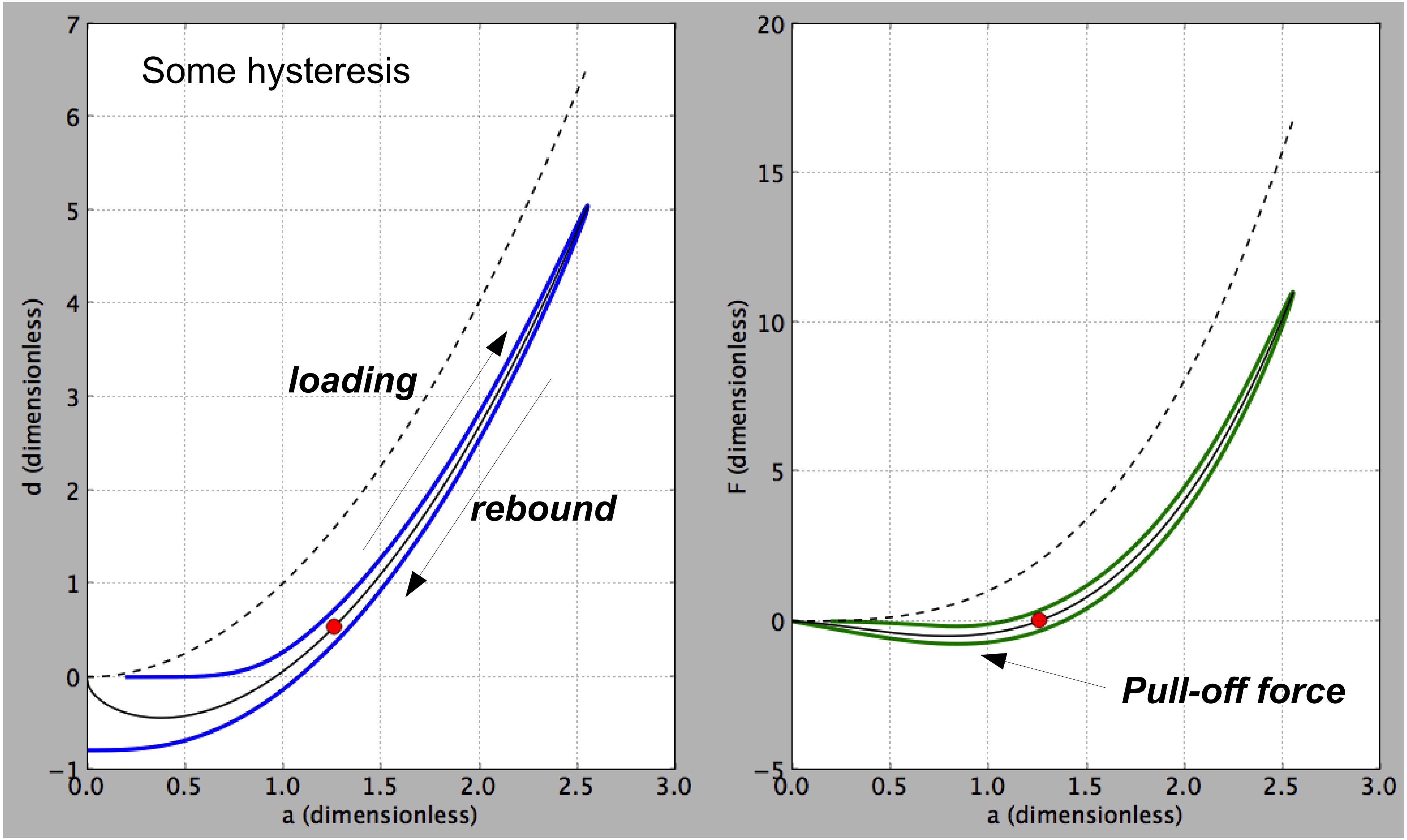


< Example; for linear viscoelastic solids, Greenwood (2004) finds this relation between the crack opening velocity and effective surface energy

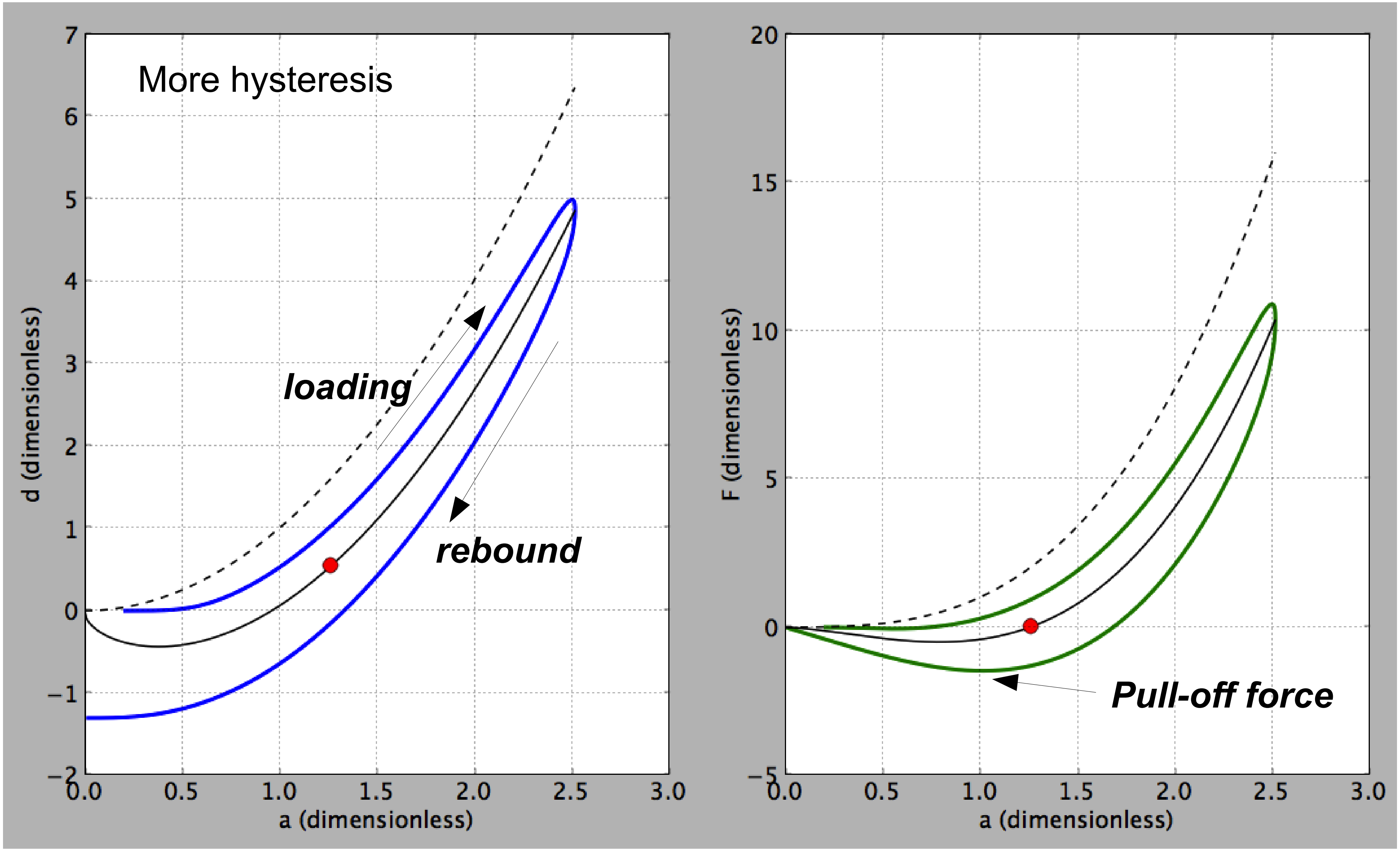
Effect on collision between spheres



Effect on collision between spheres



Effect on collision between spheres



Interesting results, but can this be applied to ice/sillicates?

- Consequences for collisions:

  (1) Create hysteresis in loading/unloading cycle

  (2) Enhanced pull-off force

  (3) Increase sticking velocity

- Consequences for rolling force

  (1) Difference in effective surface energy at the leading and trailing edge leads to a torque that opposes rolling

  (2) Size of the torque (and thus the rolling force) will depend on the *rolling velocity* and on the *contact area size*

- ***Greenwood's theory might hold for polymers / viscoelastic materials: what about ice and sillicates? What happens at the contact edge?***