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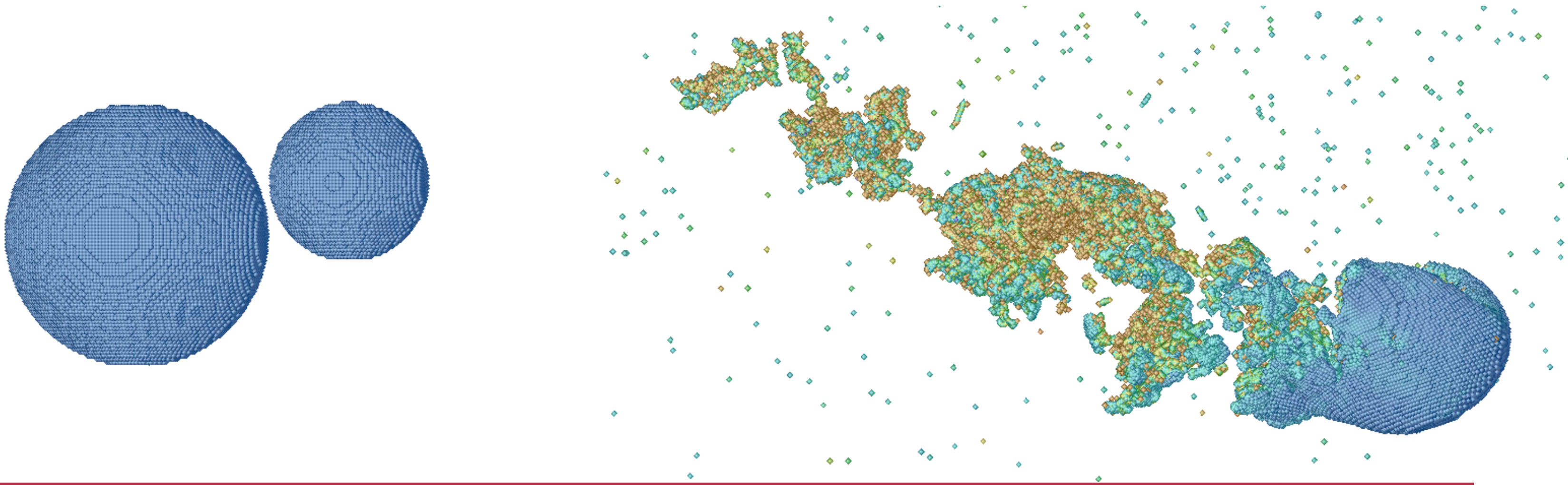

Numerical simulations of collisions between porous pre-planetesimals

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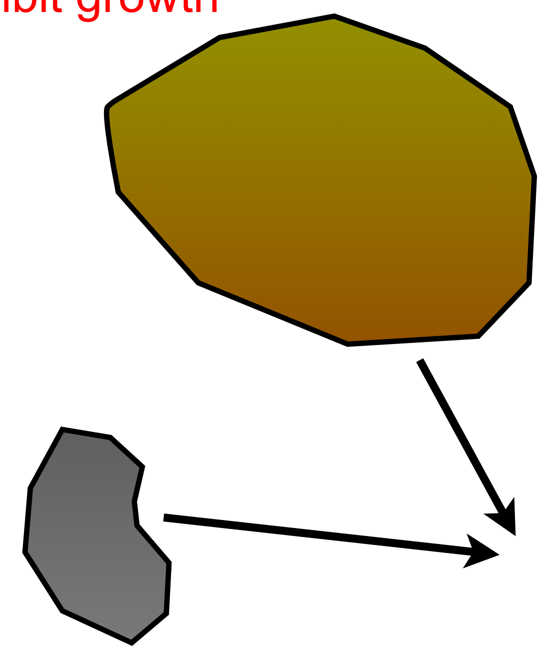
Modelling Two-Body Collisions of Porous Objects

- Aim: Parameterization of outcome of 2-body collisions

➢ In particular to get realistic sticking and fragmentation conditions, as destructive collisions, fragmentation, and bouncing inhibit growth

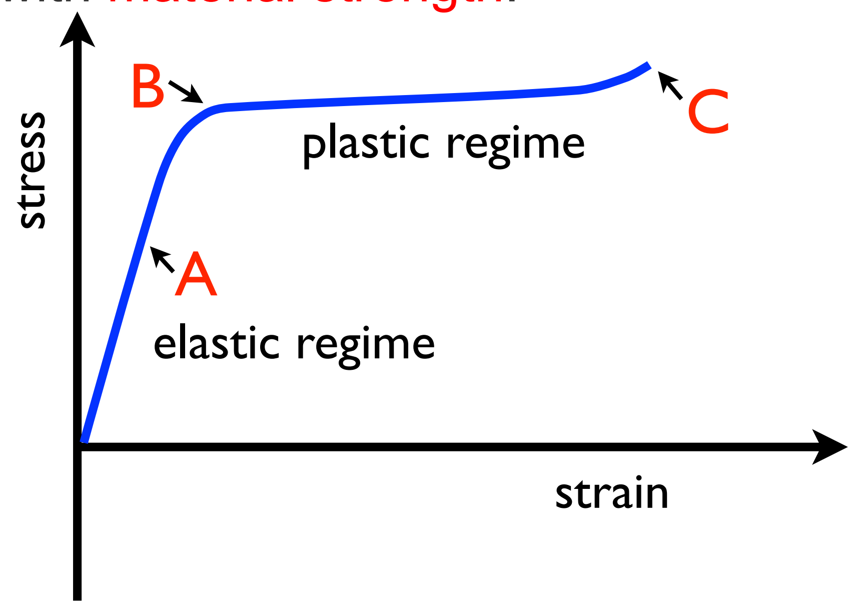
- The collisional outcome depends on:
  - Size and shape of target and projectile
  - Impact velocities
    (relative velocities due to gas drag and collision history)
  - Impact parameter / impact angle
  - Material composition and structure
    of target and projectile



- Colliding objects: Highly porous dust aggregates
  - (Porosity measured in: volume of voids / total volume
    or in filling factor: volume of matter / total volume)

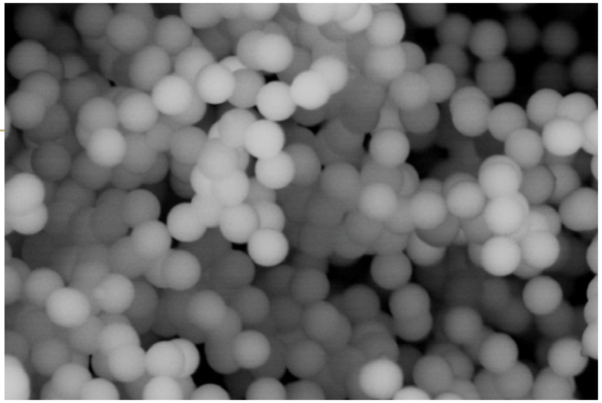
Numerical Method: Smooth Particle Hydrodynamics (SPH)

- Special version that has been extended for solid-body mechanics to include elasto-plasto dynamics with material strength:
  - A. Deviatoric stress rate proportional to strain rate (Hooke's law)
  - B. Plasticity by modifying stresses beyon the elastic limit (Yielding relations)
  - C. Damage model and brittle failure for tensile stresses

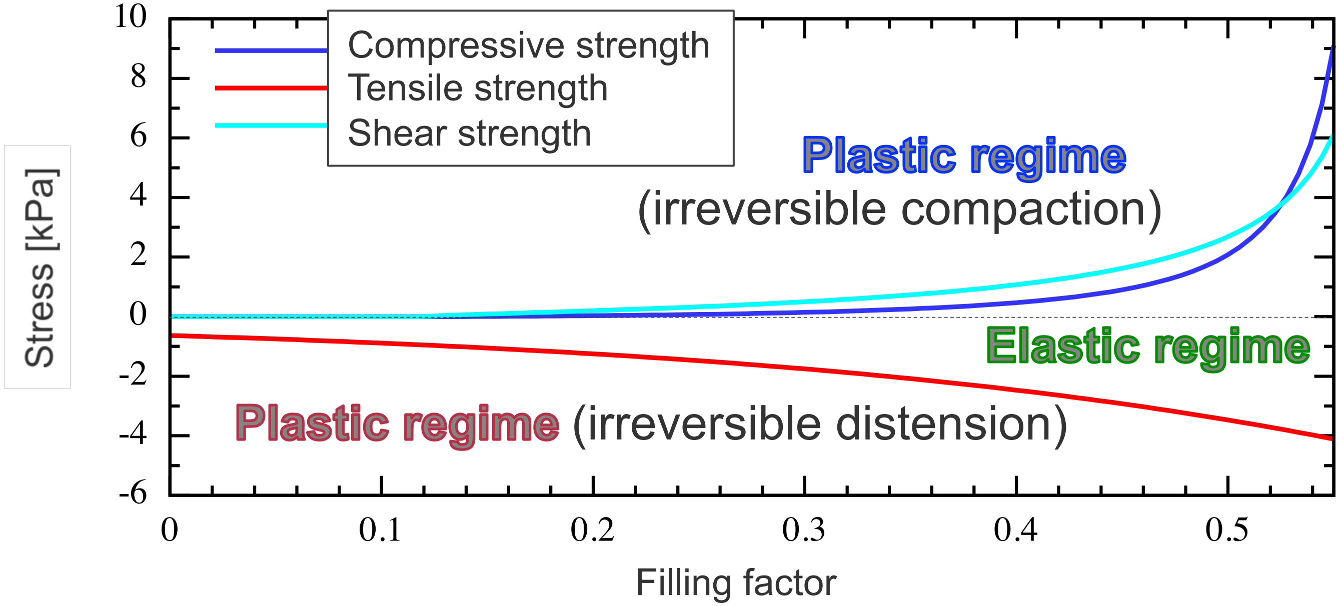


  - Suitable equation of state for complex materials
- Due to (mesh-free) particle nature of SPH: Natural reference frame for representing deformations and fragmentation.

Code Calibration and Modelling Porosity

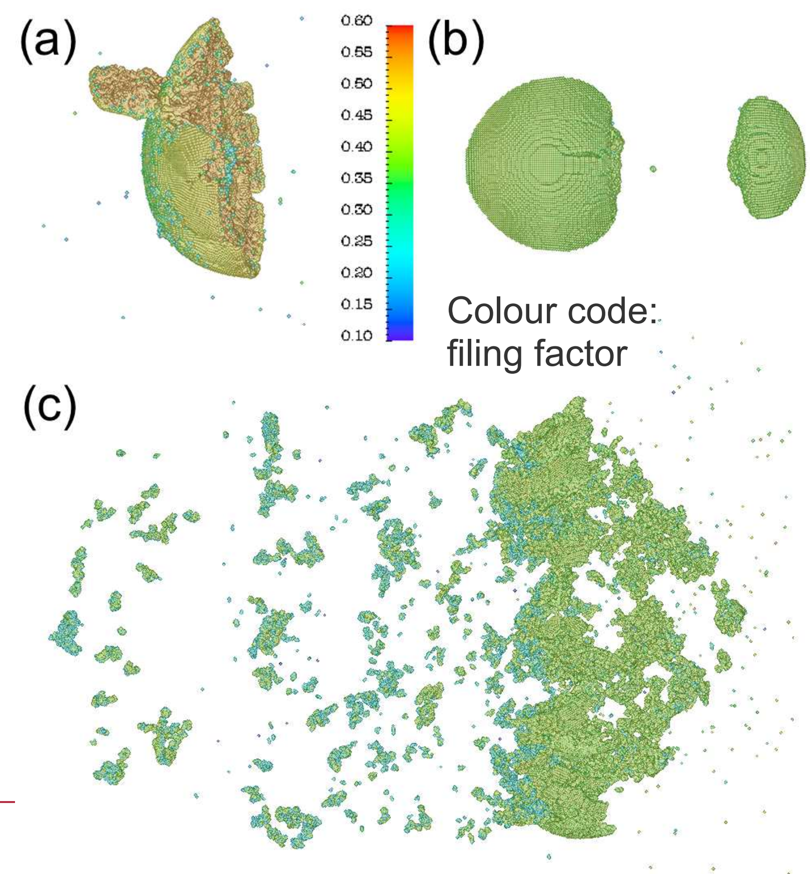


- The SPH code is calibrated for agglomerates built of mono-disperse micron-sized spherical SiO_2 dust
  (By means of lab experiments in Braunschweig; Güttler et al. 2009, Geretshauser et al. 2010)
- Porous effects are described by a simple continuum model:
  - Elastic and plastic properties depend on the filling factor



Parameter Study: Collision Velocity Threshold for Fragmentation

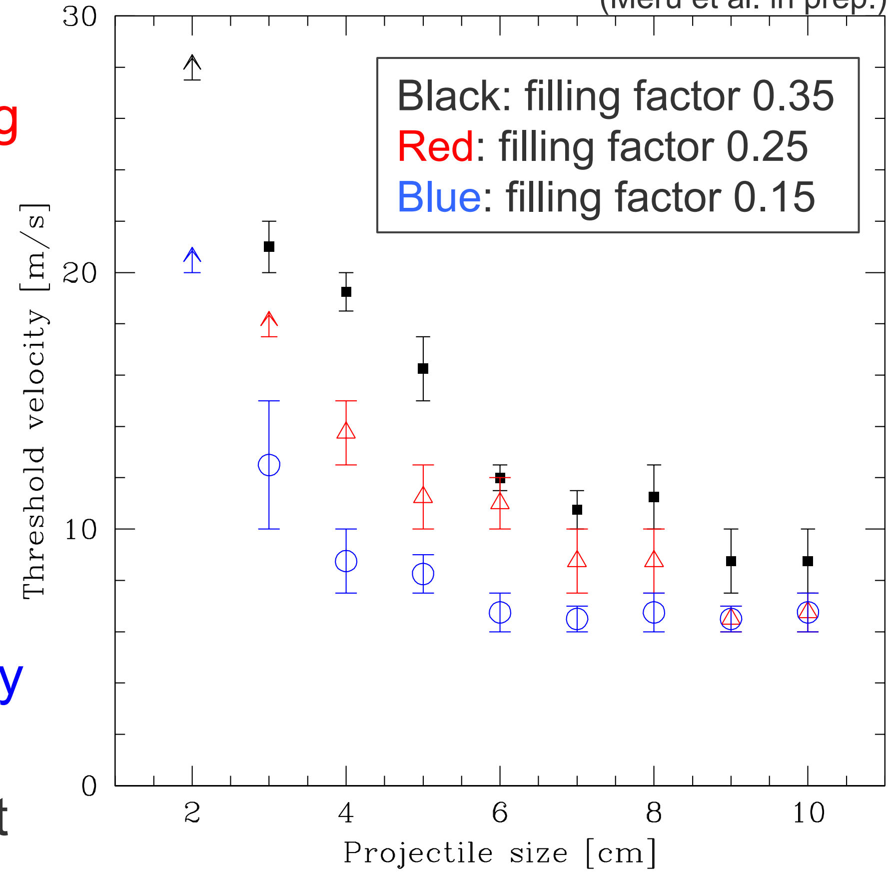
- Aim: Find collision velocity above which the impact results in destruction (fragments are smaller than initial target)
- Parameters for target and projectile:
  - Homogeneous dust spheres
  - Identical filling factors (from 0.15 to 0.55)
  - Head-on impact
  - Different size ratios between projectile and target (from 1:5 to 1:1)
- Examples of collisional outcome:
  - (a) Sticking
  - (b) Bouncing (with mass transfer)
  - (c) Fragmentation



Results 1: Dependence of Fragmentation Velocity on Size Ratio

- The fragmentation threshold velocity decreases with increasing projectile size (fixed target size)
- Reason:
  - Impact energy decreases with decreasing projectile size
  - The target can absorb small projectiles as a whole
- For high and intermediate porosity (small and medium filling factors) the curves have similar shape but differ in value

(Meru et al. in prep.)

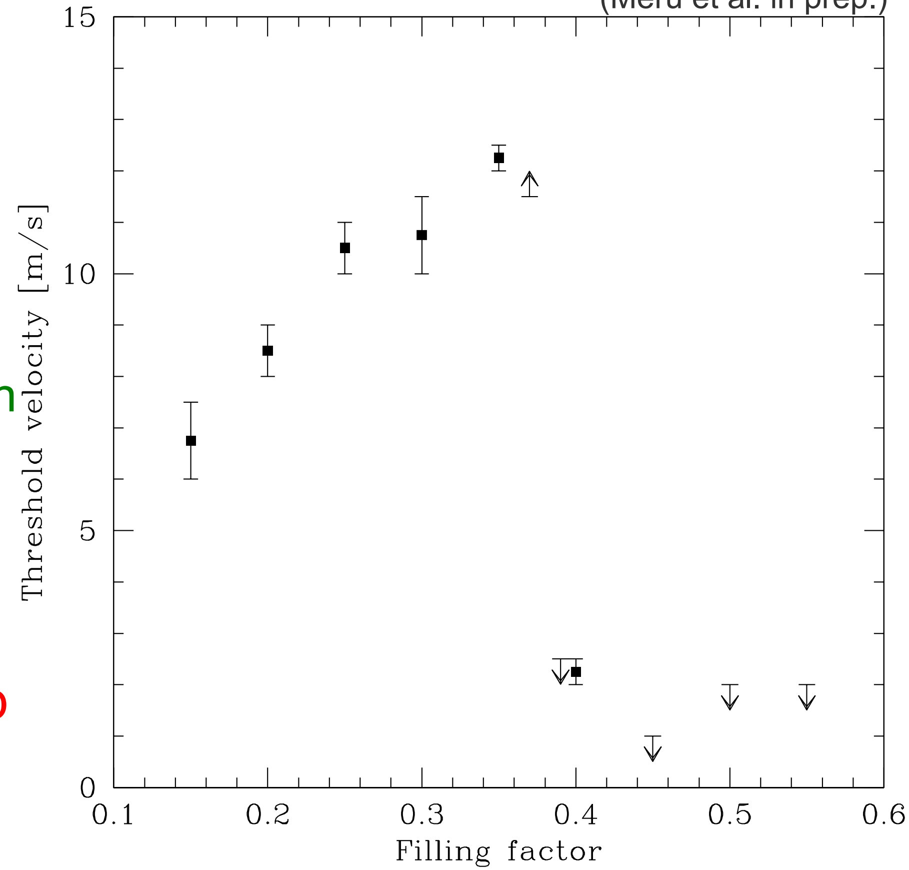


(Target size: 10 cm)

Results 2: Dependence of Fragmentation Velocity on Porosity

- At high porosity, the fragmentation threshold velocity increases with filling factor
  - The compressive strength is low, therefore impact energy can easily be dissipated by plastic deformation
  - Tensile and shear strength increase, therefore the stability of the objects increases
- At filling factor ~ 0.37, a sharp drop occurs, and for low porosity the threshold is low (≤ ~ 1 m/s)

(Meru et al. in prep.)

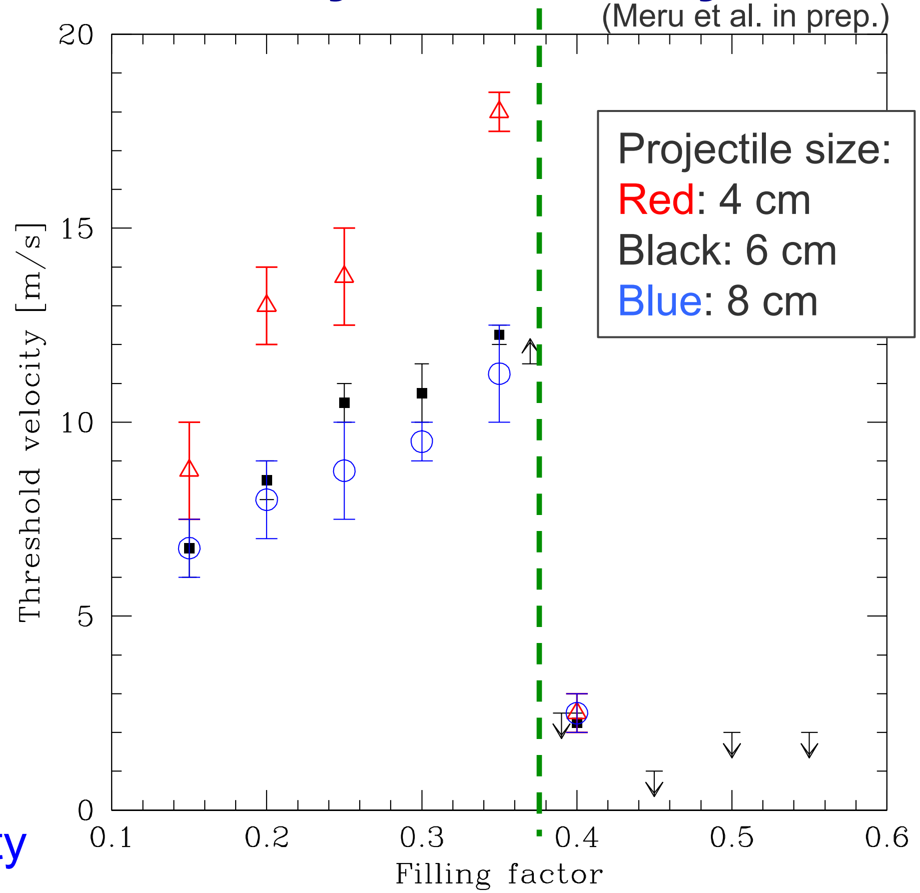


(Target size: 10 cm, projectile size: 6 cm)

Results 2:
Dependence of Fragmentation Velocity on Porosity

- The drop in threshold velocity is independent of size ratio between projectile and target
- Complex interplay between elastic and plastic effects:
  - With increasing compressive strength, less impact energy is dissipated and more is stored in elastic loading
  - With increasing bulk modulus, the aggregates become stiffer
  - High strengths lead to larger density waves (and local variations)

(Meru et al. in prep.)

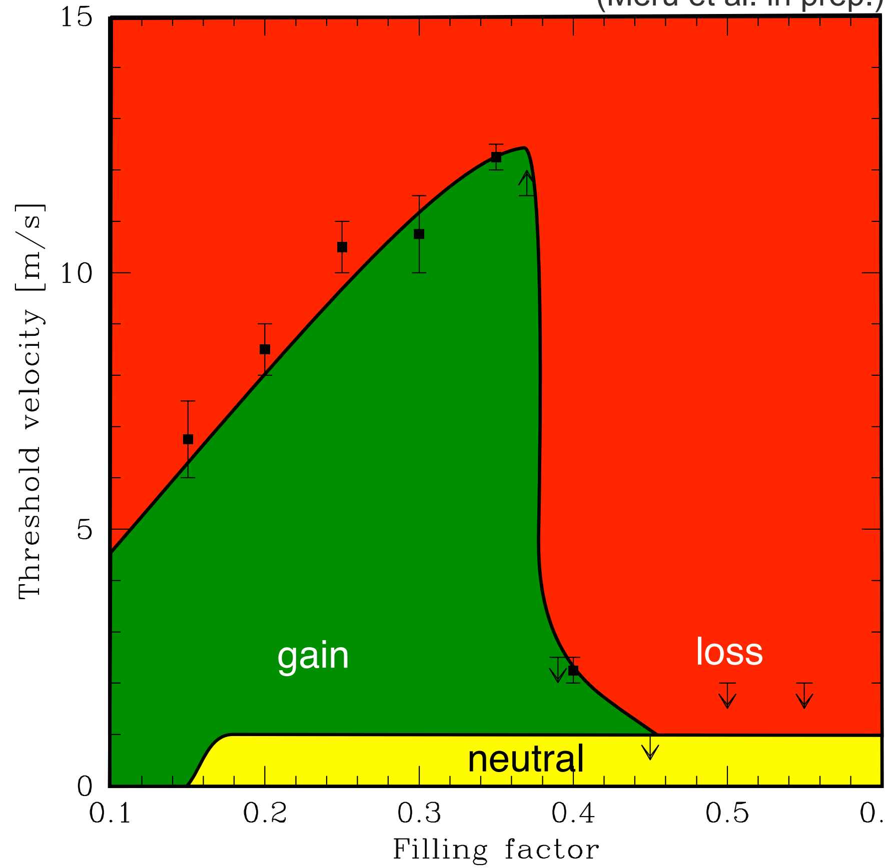


(Target size: 10 cm)

Results 2:
Dependence of Fragmentation Velocity on Porosity

- Regimes of collisional outcome:
  - Gain: Growth (sticking, transfer)
  - Loss: Fragmentation
  - Neutral: Bouncing (partly with mass transfer)
- Higher elastic loading and stiffer aggregates increase the probability of bouncing
- Less dissipated impact energy decreases the probability of sticking
- Larger local variations in strengths due to large waves increase the probability of fragmentation

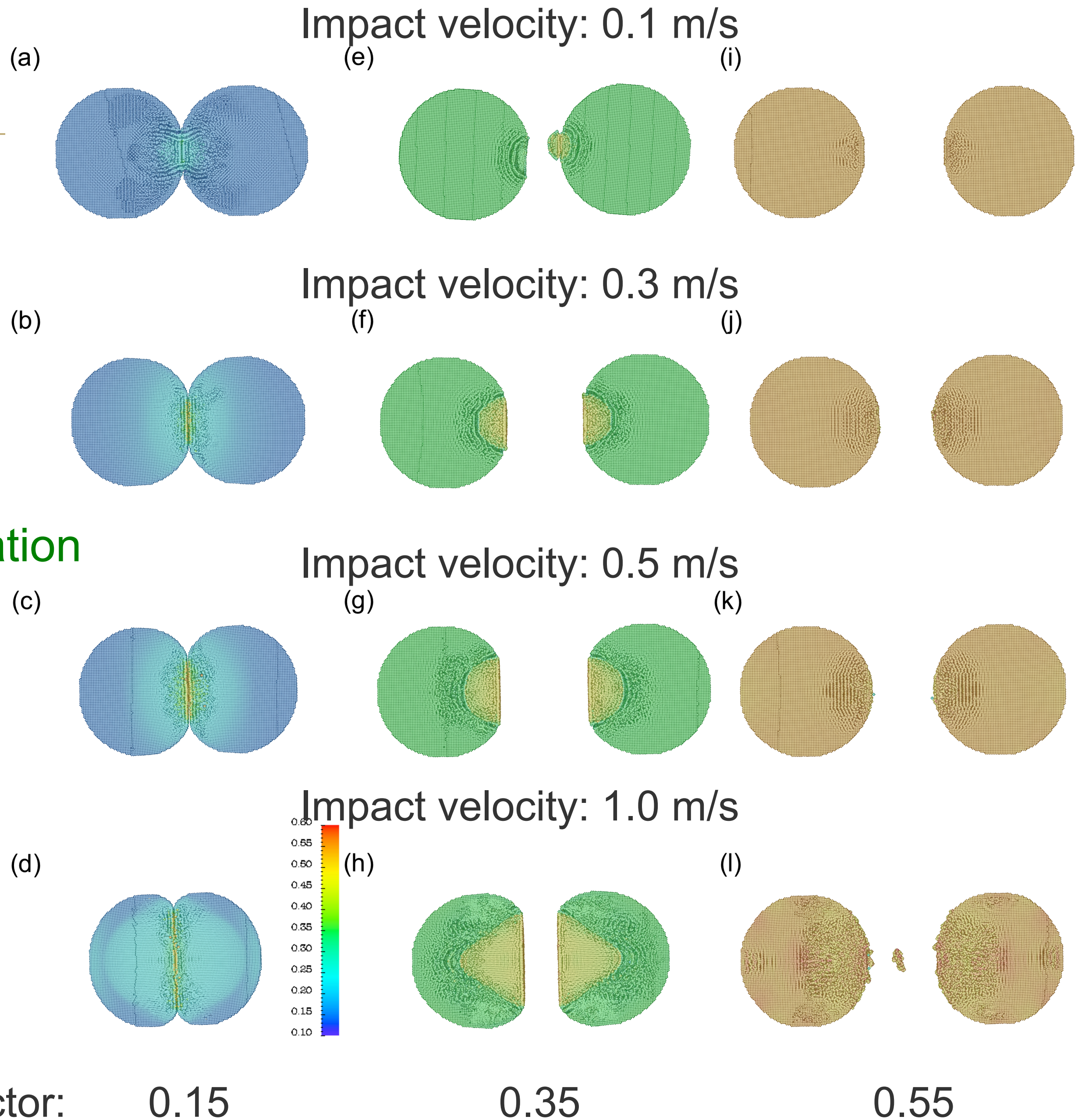
(Meru et al. in prep.)



(Target size: 10 cm, projectile size: 6 cm)

Bouncing and Sticking

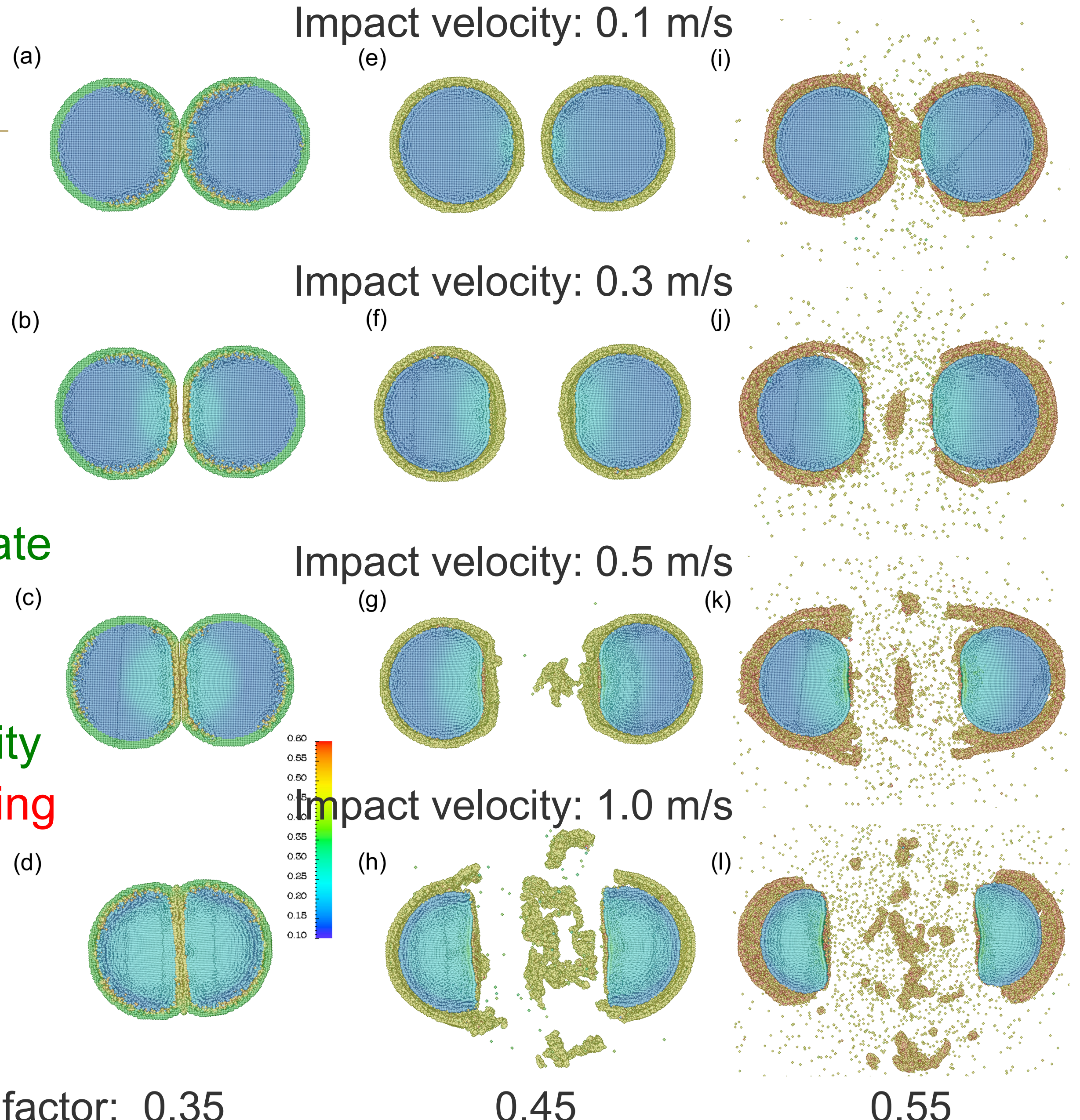
- Homogeneous objects with low impact velocity:
  - High porosity: Always sticking due to dissipation and deformation
  - Medium porosity: Bouncing with plastic deformation
  - Low porosity: Always elastic bouncing (with small mass transfer)



(Geretshauser et al. accepted)

Bouncing with Hard Shells

- Highly porous objects (filling factor 0.15) with a compacted shell:
  - Shells with intermediate porosity generally do not prevent sticking
  - Shells with low porosity always lead to bouncing while the shell rather breaks than deforms



(Geretshauser et al. accepted)

Summary

- For the outcome of collisions between pre-planetesimals, the porosity of the objects is important
- Around intermediate porosity, a significant and sudden change in collision behaviour is observed
- The (quantitative) results are very sensitive to the material parameters (⇒ caution with conclusions based on special values)

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