A Growth Model for Protoplanetary Dust Aggregates Based on Laboratory Experiments

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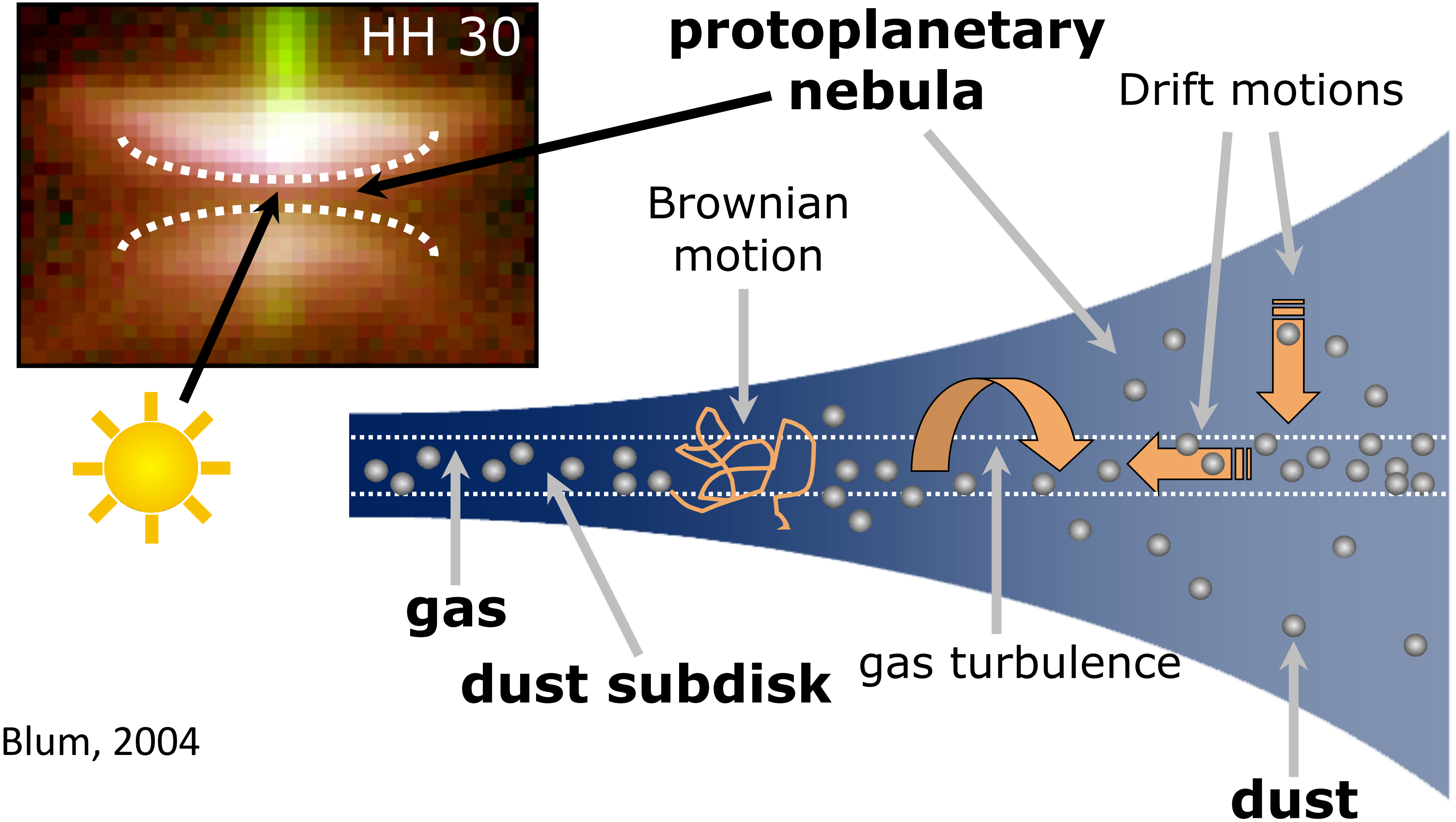
IGEP TU Braunschweig Institut für Geophysik und extraterrestrische Physik

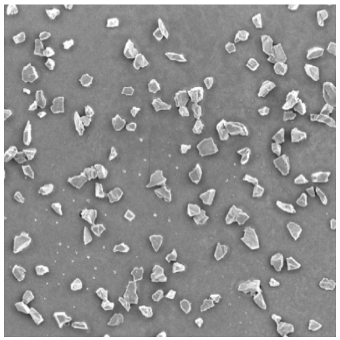
Protoplanetary Disk



Blum, 2004

From Dust to Planets

dust
~1 µm

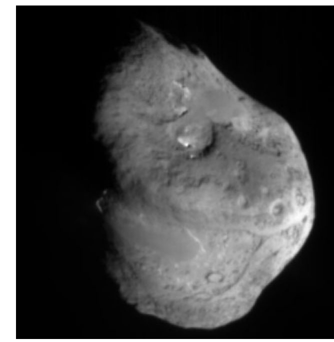


Poppe et al., 2000a

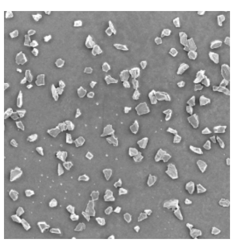
agglomeration →

Interaction with gas dominant
gravitation negligible

planetesimals
e.g. 1 km

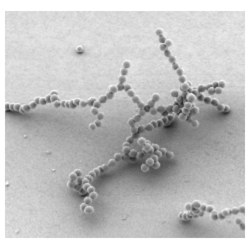


Comet Temple 1
© NASA/JPL-Caltech/UMD



Poppe et al., 2000a

→



Blum et al., 1998

→

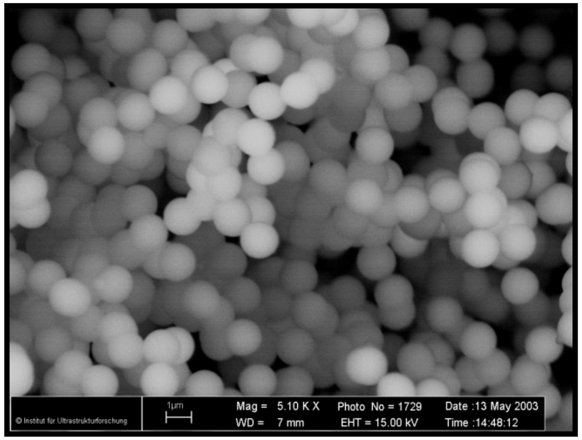
Dominik & Tielens, 1997
see also: Blum & Wurm, 2000

→ **?**

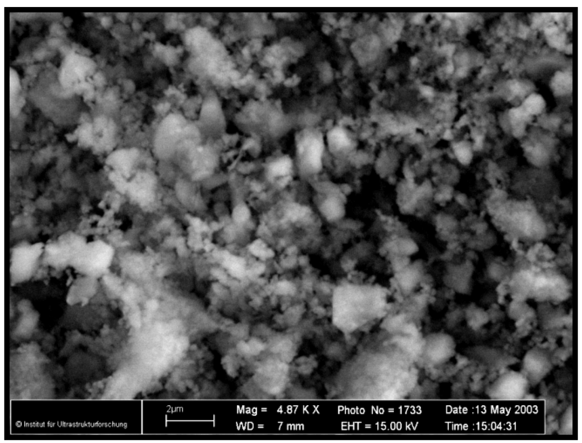
Outline

1. The Collision Model
   laboratory experiments
2. Results: Application of the Model
   consequences for the evolution of dust
3. New Experiments
   future improvements of the model

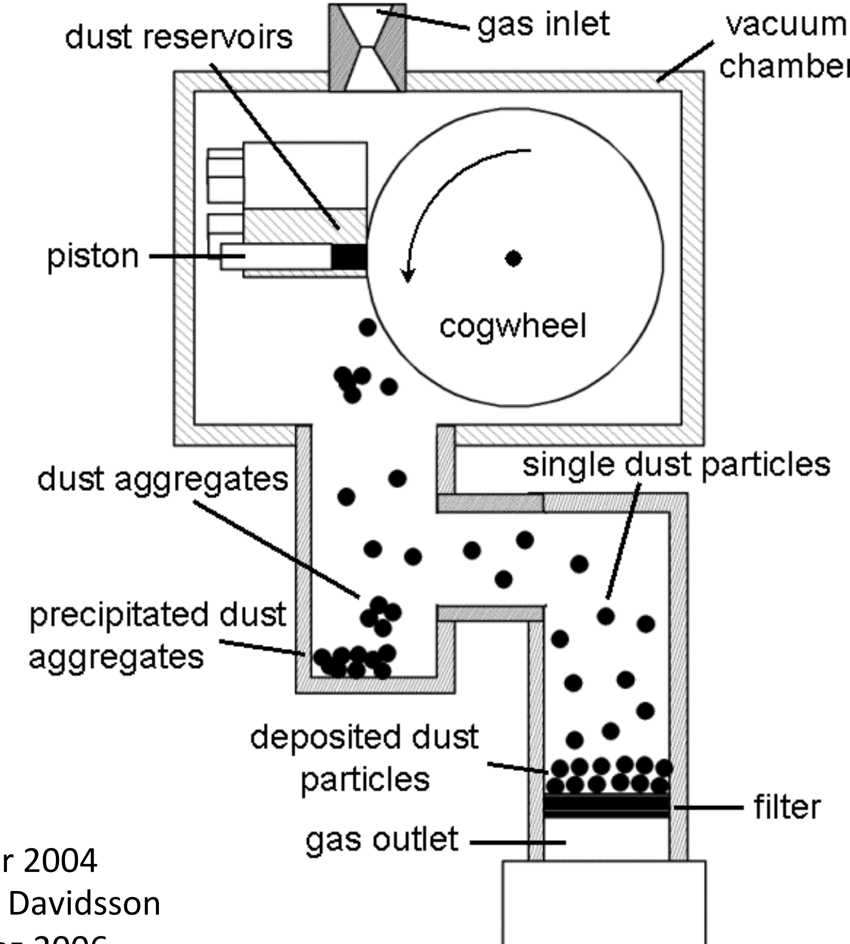
Analog Material



spherical SiO_2 grains, Ø 1.5µm, ϕ=0.15



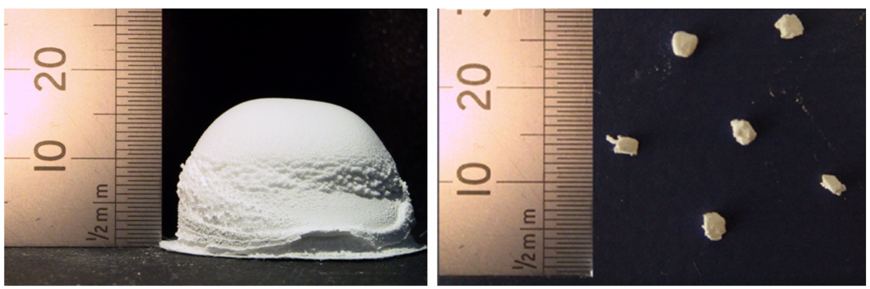
irregular SiO_2 grains, Ø 0.1-10µm, ϕ=0.07



Blum & Schräpler 2004
Blum, Schräpler, Davidsson & Trigo-Rodriguez 2006

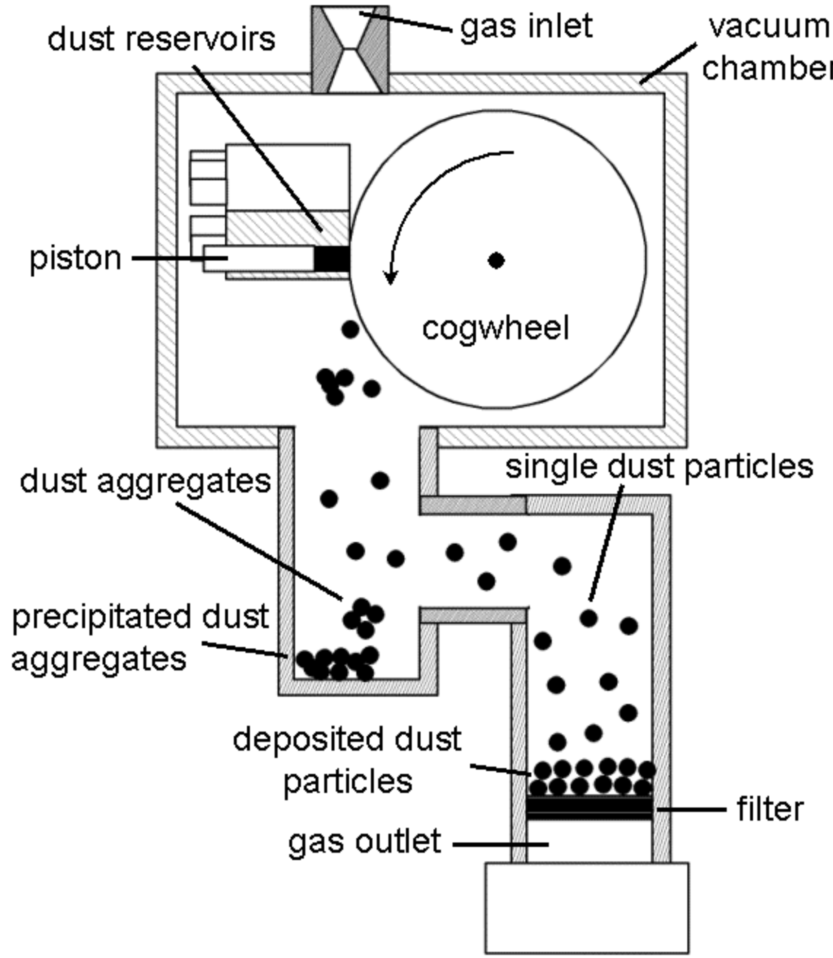
Analog Material

Random ballistic deposition (RBD) of single dust grains as an idealized representative of polydisperse growth (BPCA)



Langkowski et al., 2008

high porosity dust aggregate and fragments of those (Ø 25 mm, ϕ=0.15)



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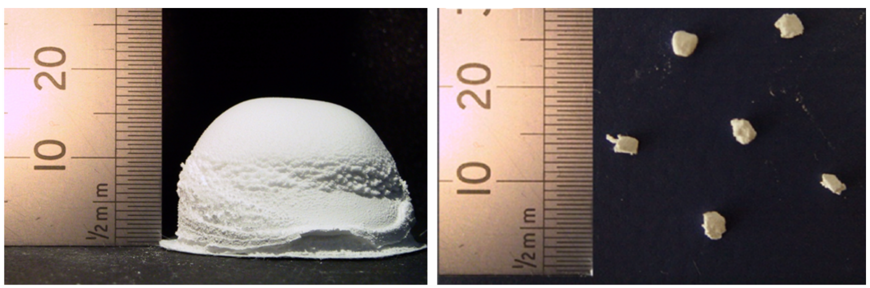
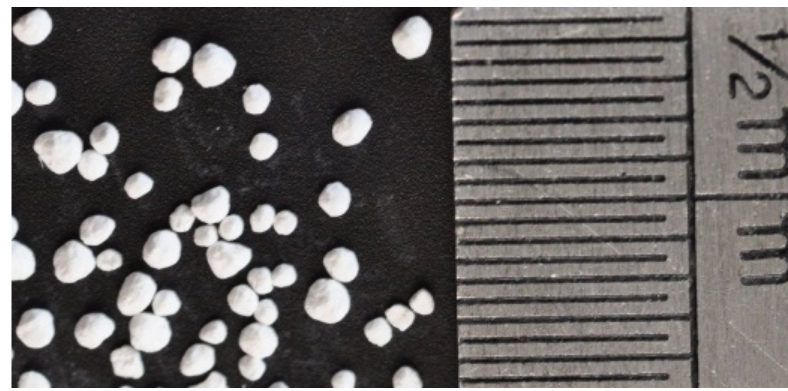


Langkowski et al., 2008

high porosity dust aggregate and fragments of those
(Ø 25 mm, ϕ=0.15)

Intermediate porosity aggregates formed in a storage container representing a long collision history



Weidling et al., subm., Icarus

millimeter sized pebbles with ellipsoidal shape, ϕ=0.35

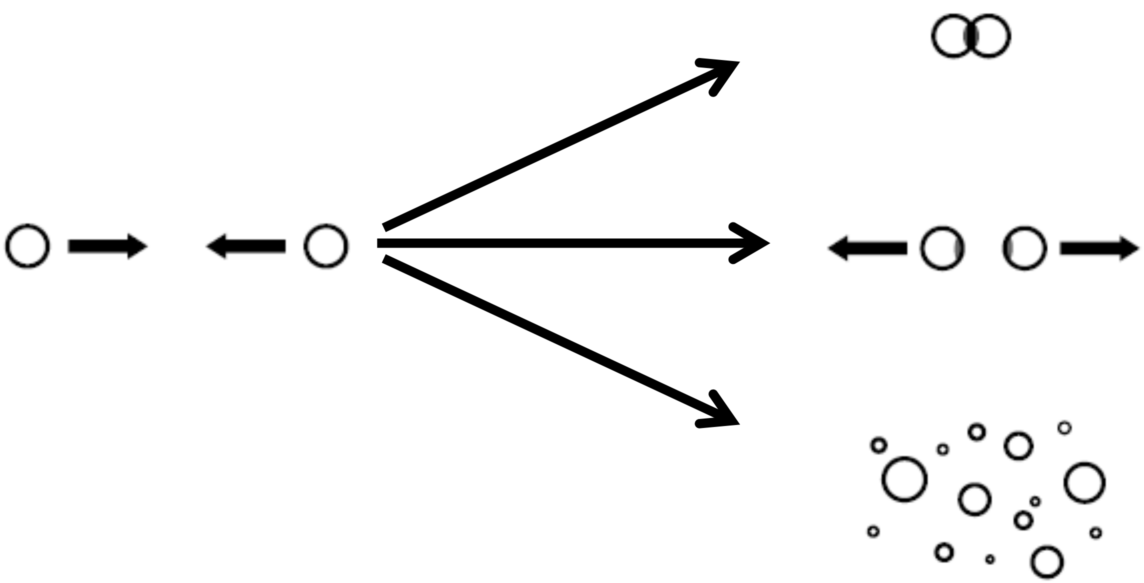
Laboratory Experiments

collision experiment

(chose aggregate mass, size ratio, porosity, collision velocity, …)

collisional outcome

(e.g., sticking, bouncing, fragmentation, or something unexpected)

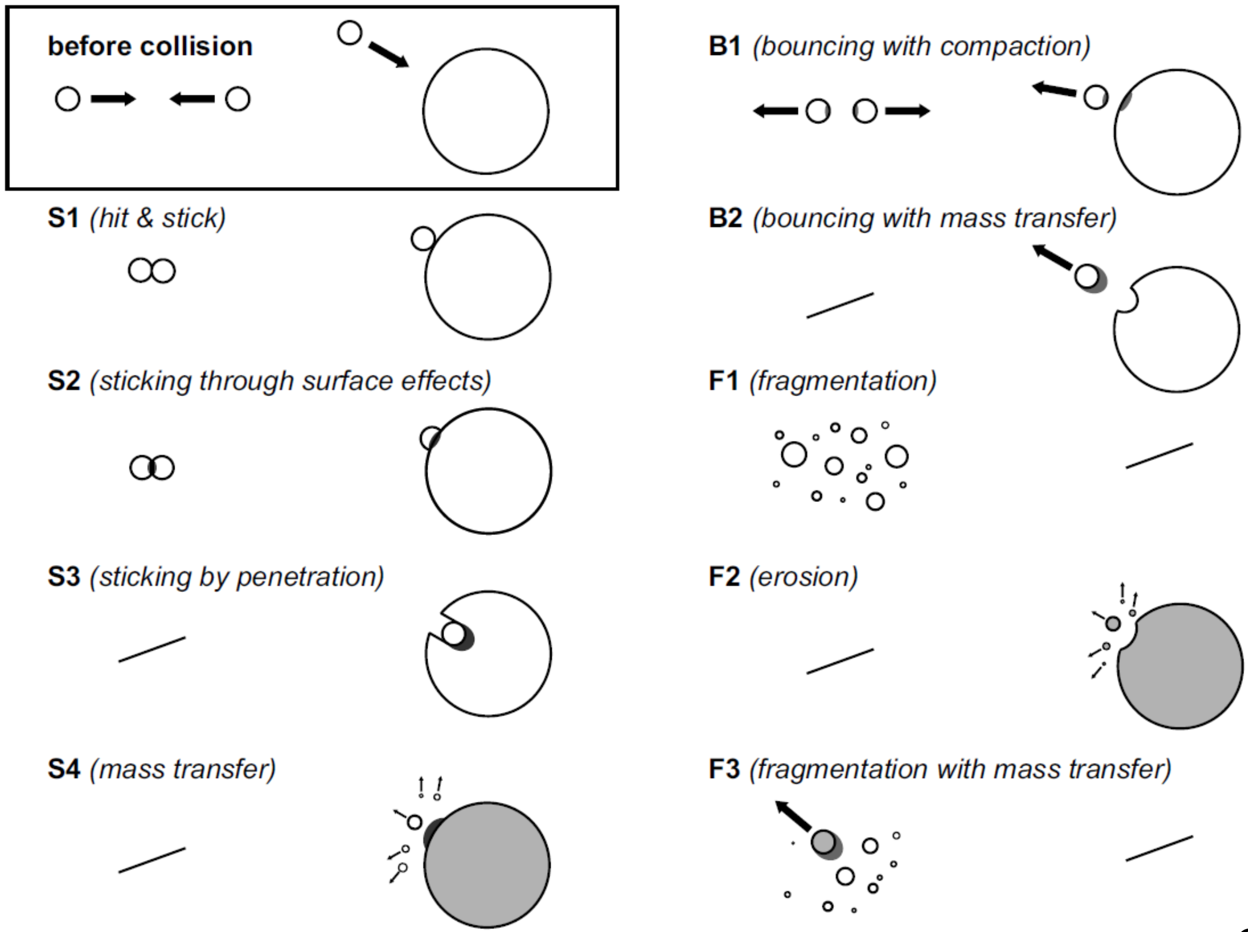


<u>sticking</u>
threshold velocity, new mass, new porosity, …

<u>bouncing</u>
threshold velocity, new porosity, …

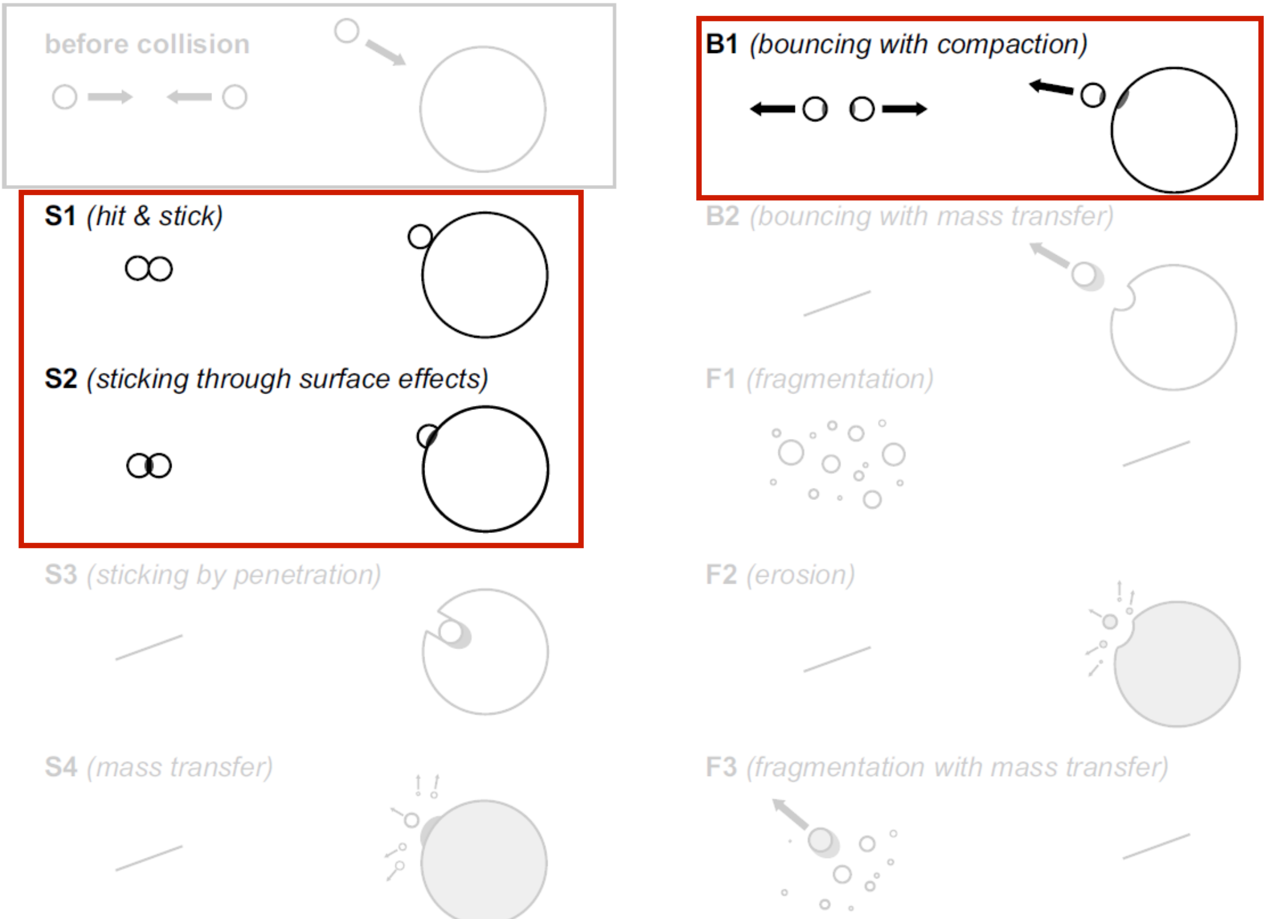
<u>fragmentation</u>
fragment size distribution, fragment velocities, porosities, …

Overview on Collisional Outcomes



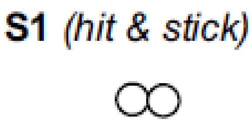
Güttler et al., 2010

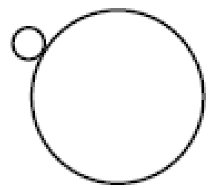
Overview on Collisional Outcomes



Güttler et al., 2010

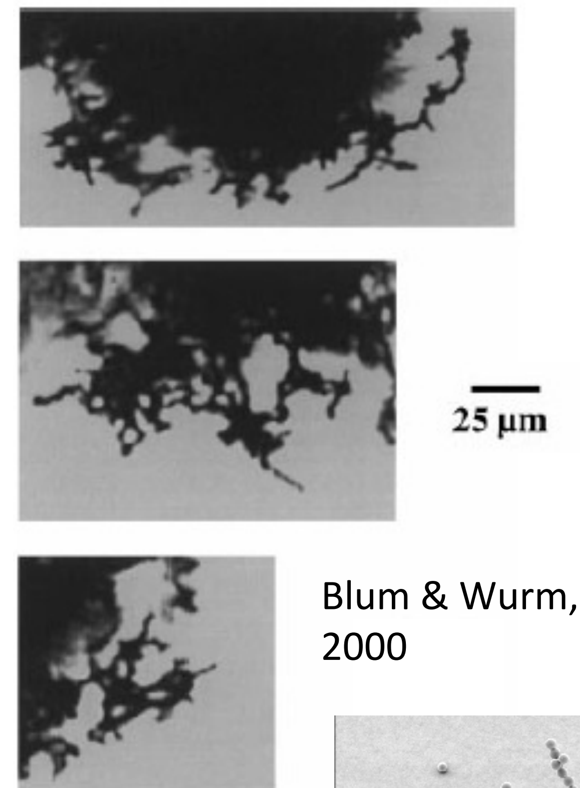
S1: Hit & Stick



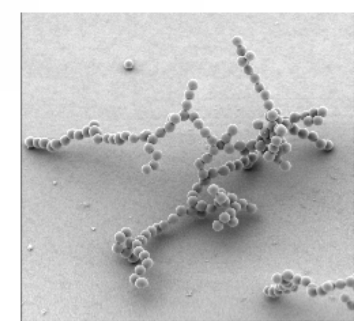


- Sticking without any restructuring if $E_{impact} < 5 \cdot E_{roll}$
- Physical description and simulation: Dominik & Tielens (1997)
- Experiments: Blum & Wurm (2000)

Blum & Wurm, 1998

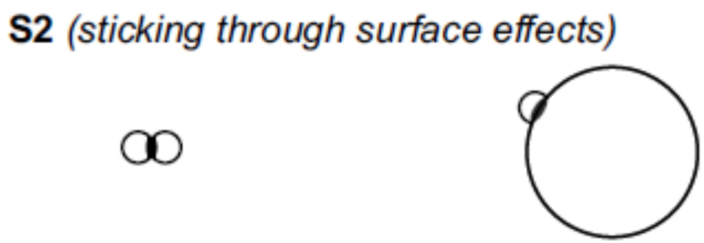


Blum & Wurm, 2000

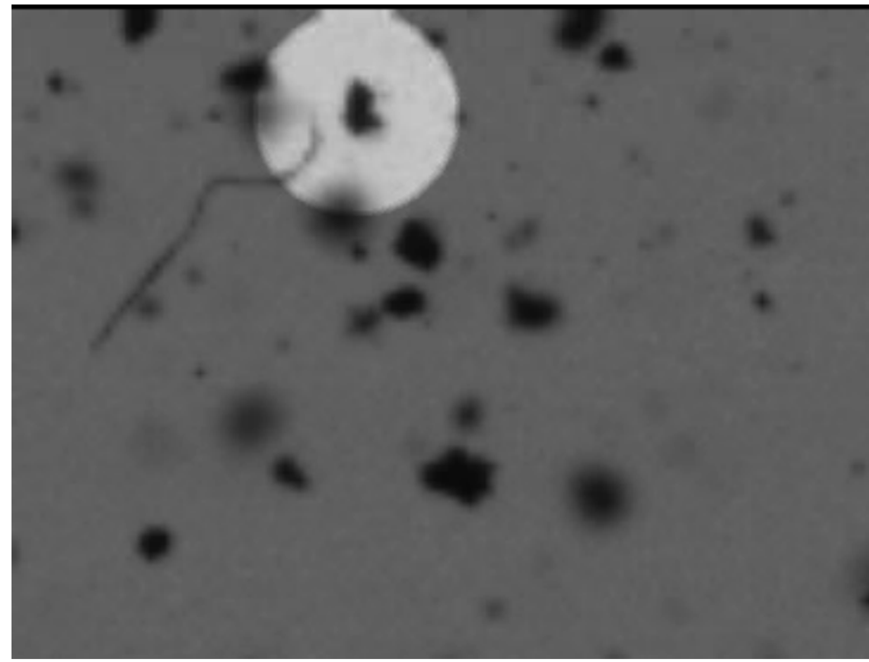


Blum et al., 1998

S2: Sticking by Surface Effects



- Collisions can lead to sticking although the hit-and-stick threshold velocity is exceeded
- Explanation: aggregate is compacted, contact area increases
  → more contacts support sticking



size: 0.2 mm; velocity: 0.24 m/s

Kothe, Güttler & Blum, unpublished data

B1: Bouncing with Compaction I

B1 *(bouncing with compaction)*

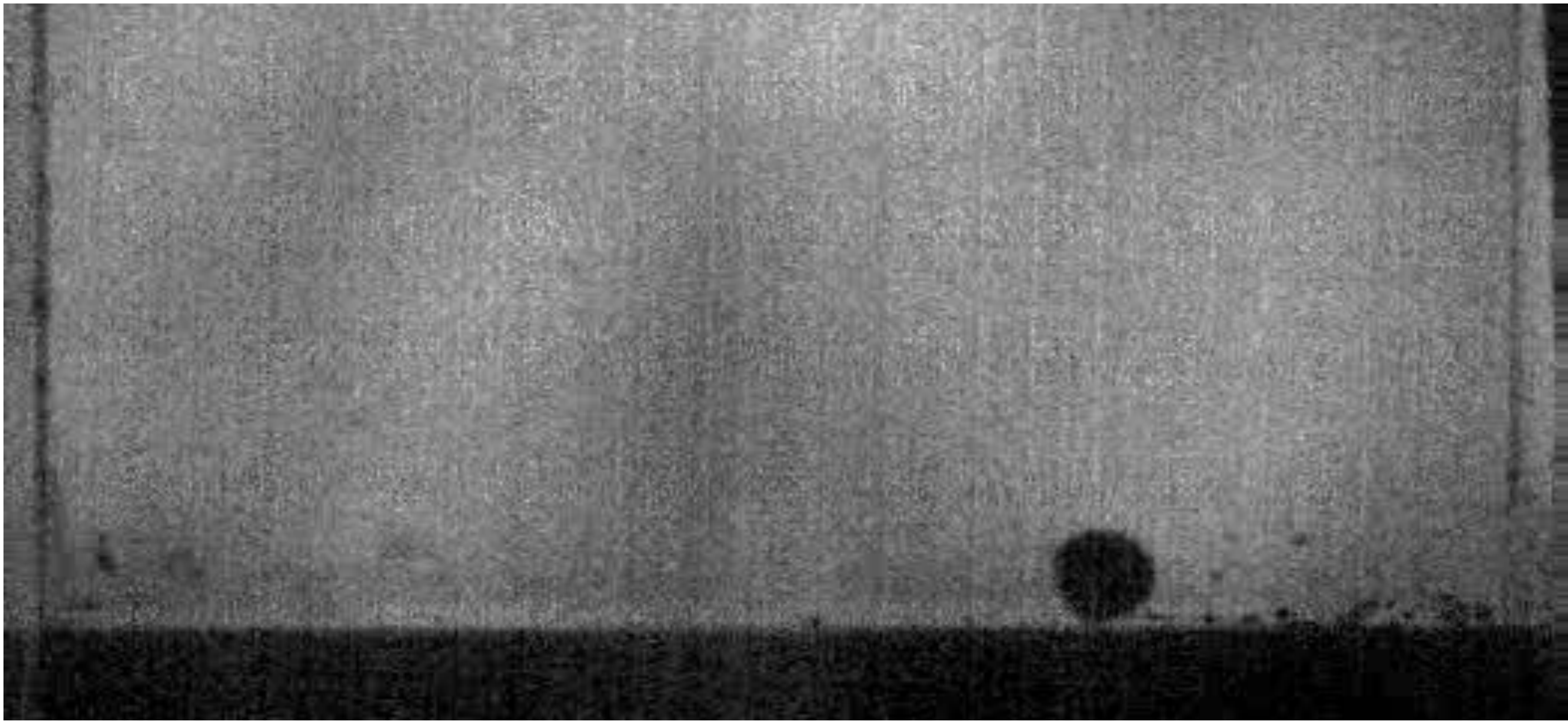
- Collisions between mm-sized aggregates hardly lead to sticking
- Bouncing for low velocities (<1m/s)

v_{rel} = 0.4 m/s

5 mm

Heißelmann, Fraser & Blum, 2007

B1: Bouncing with Compaction II



Weidling, Güttler, Blum & Brauer, 2009

<v> = 20 cm/s   4 mm

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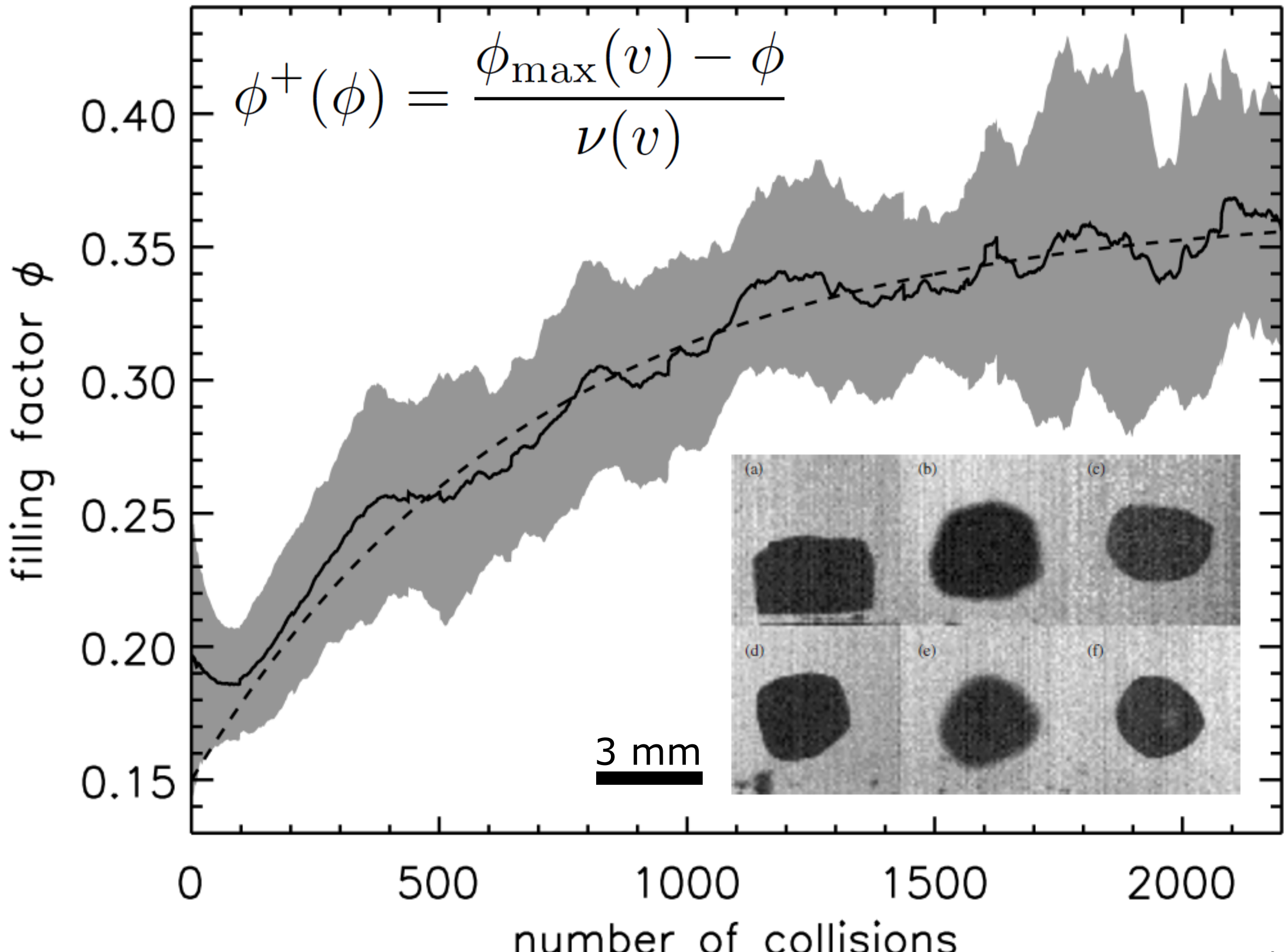
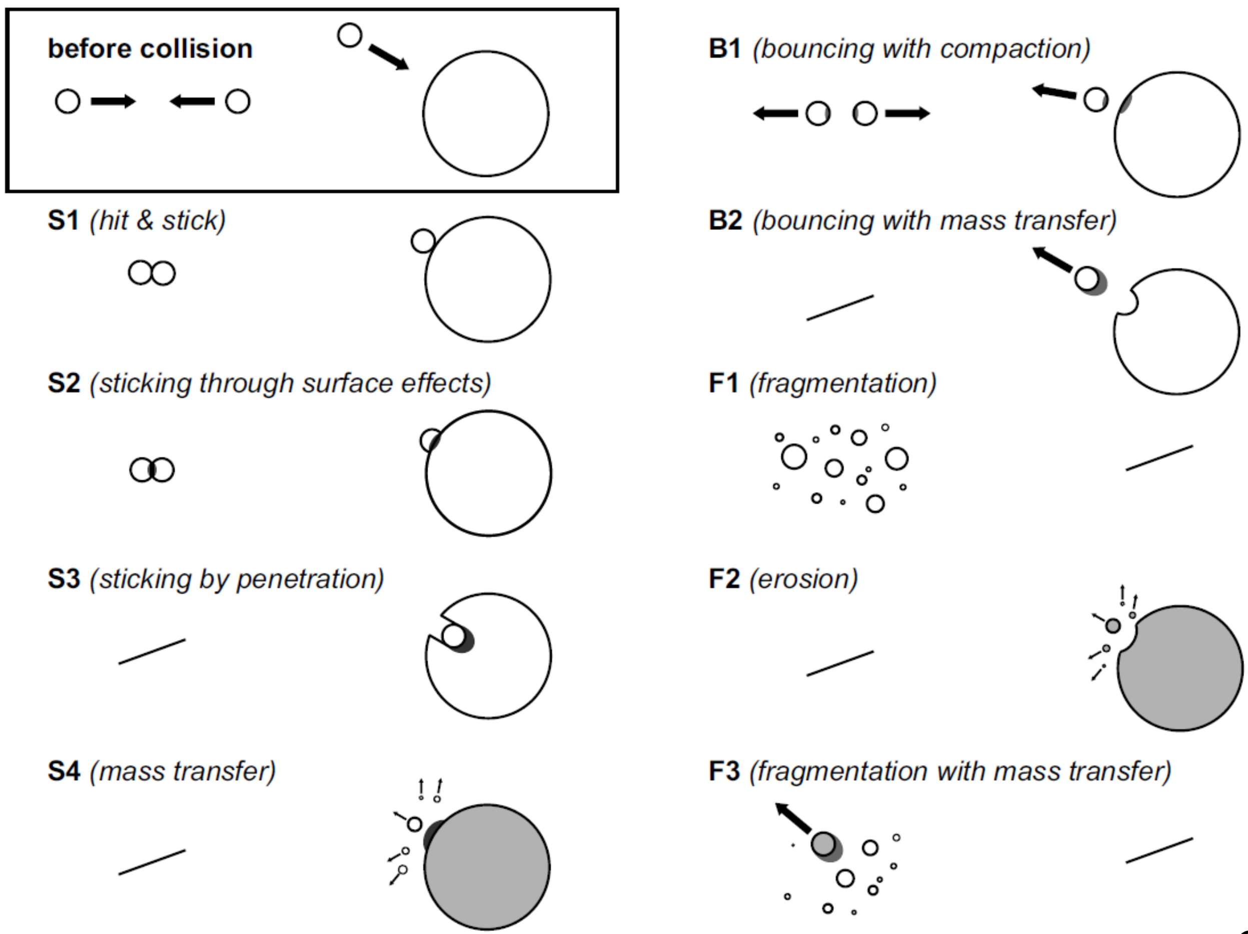
B1: Bouncing with Compaction II

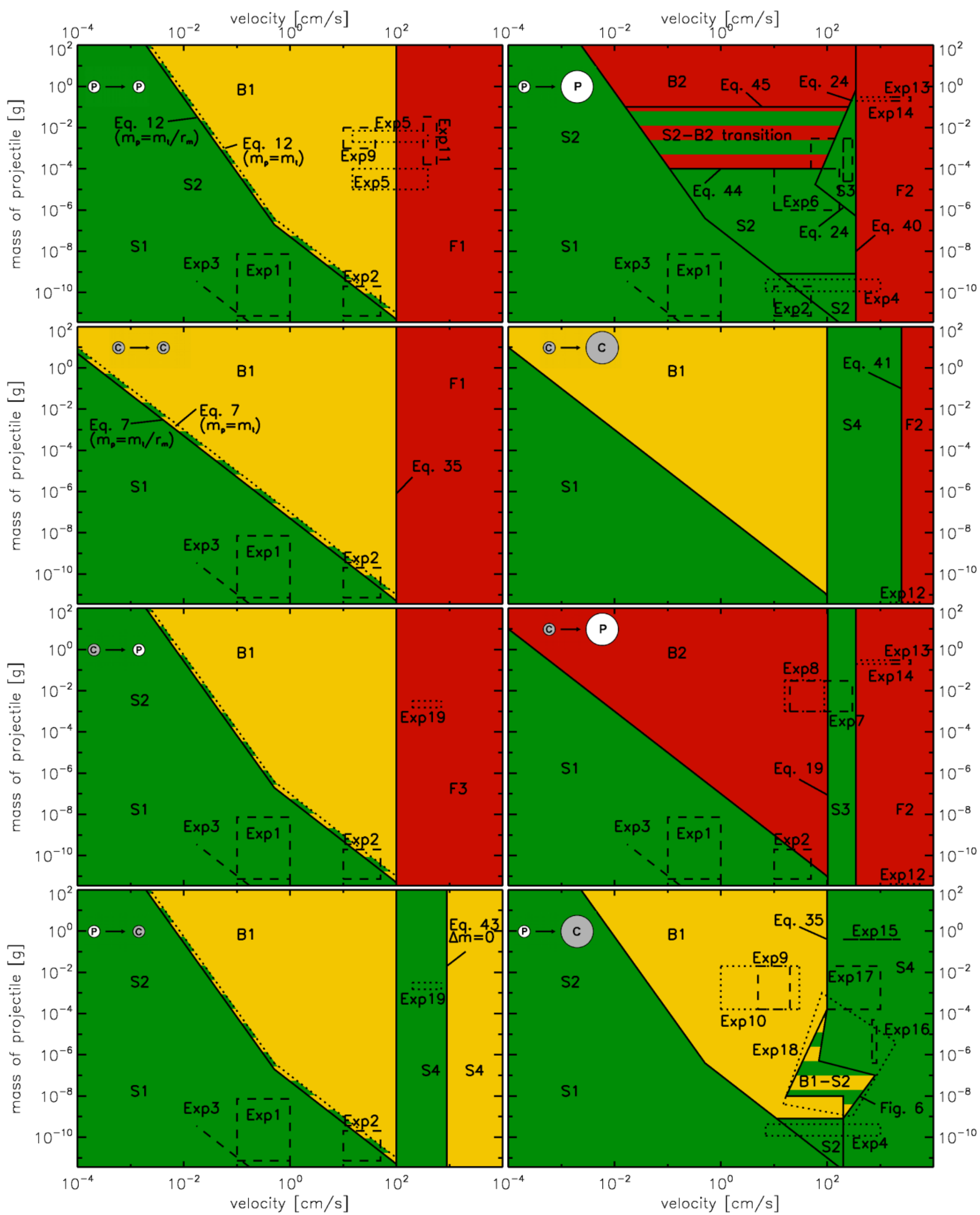


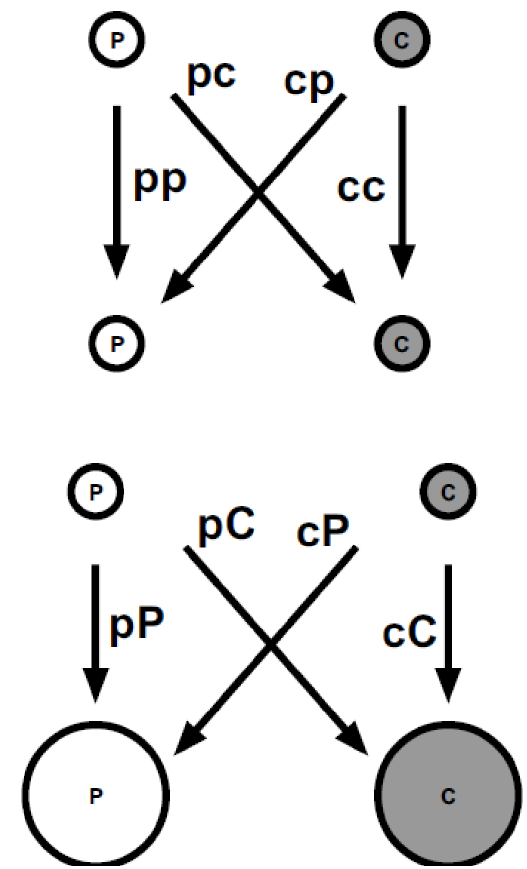
Weidling et al., 2009

Overview on Collisional Outcomes



Güttler et al., 2010

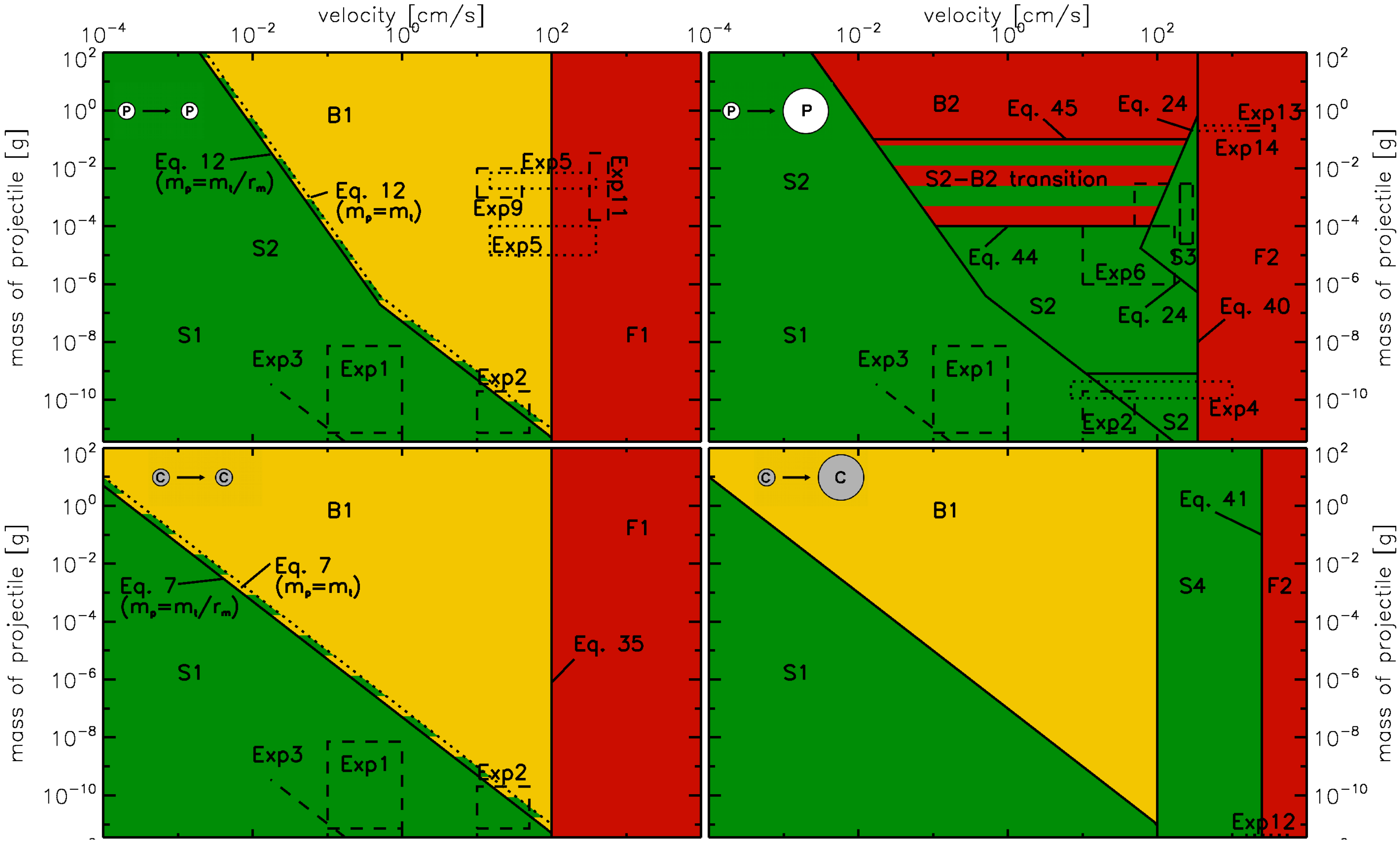




x axes: velocity
10^{-4} .. 10^{4} cm/s

y axes: mass
10^{-11} .. 10^{2} g

The Collision Model



Güttler & Blum: A Growth Model for Protoplanetary Dust Aggregates

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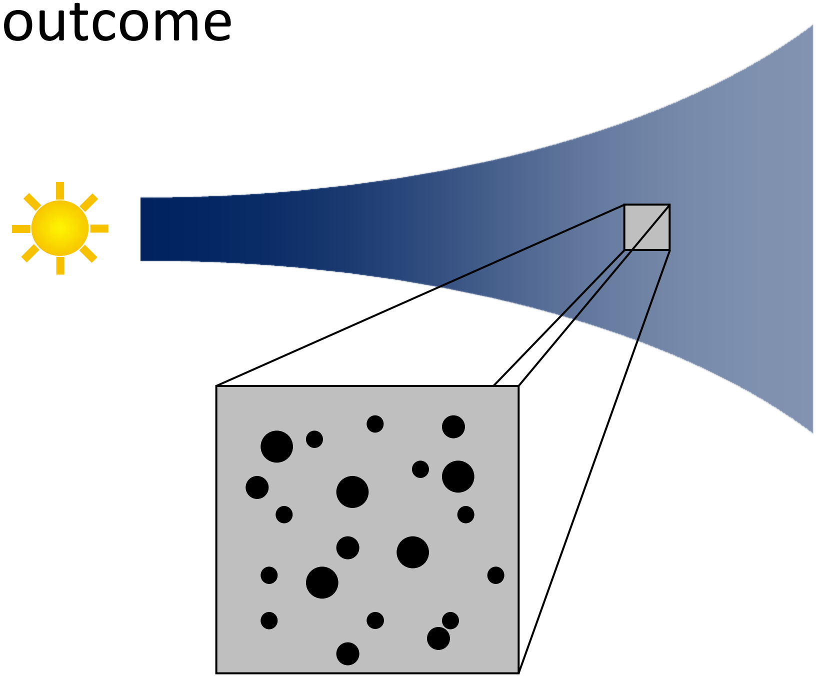
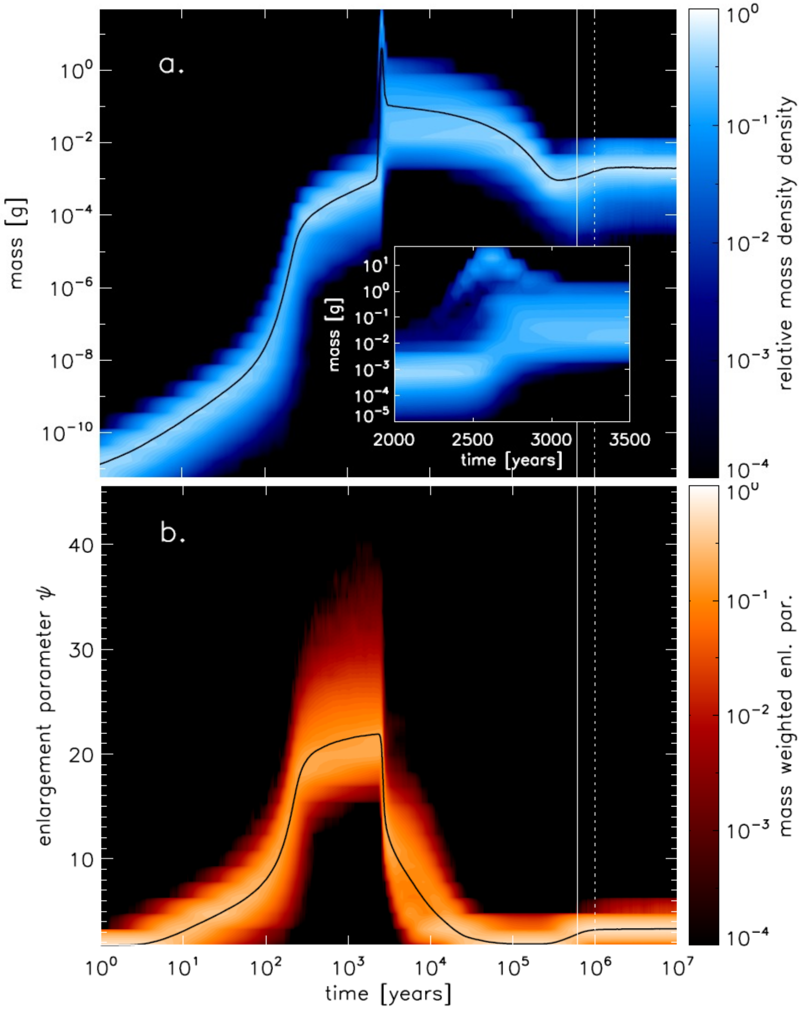
The Monte-Carlo Growth Model

- Dust growth in a box in the protoplanetars disk
- Fast Monte Carlo code (Zsom & Dullemond, 2008)
- Aggregates possess physical properties (i.e. mass, porosity), which determine the collisional outcome
- Monte Carlo character: collision probabilities determine the next collision to compute



- Model parameters: $r=1AU$; $\alpha=10^{-4}$; $T=200K$; $\Sigma_0=1700\ g/cm^2$ (MMSN)

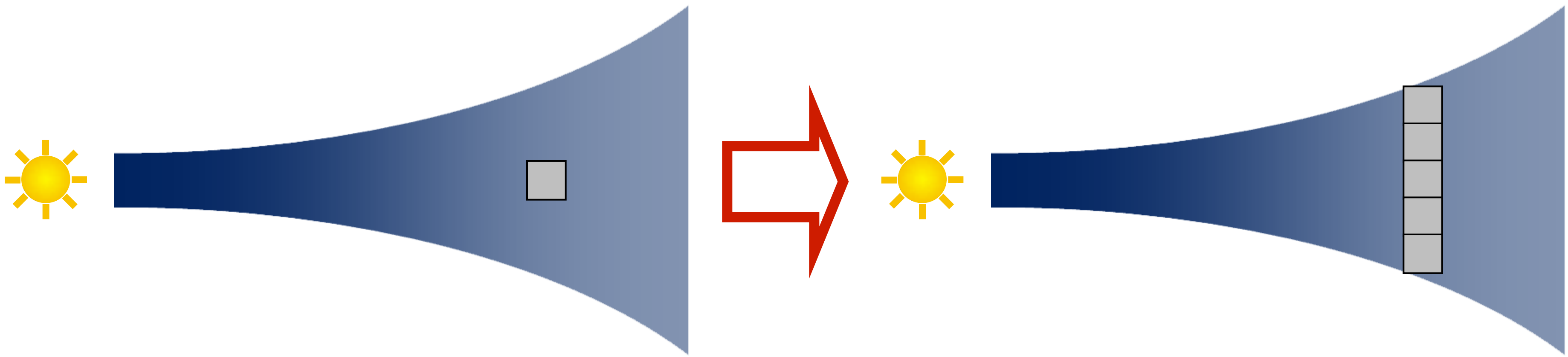
How do the Aggregates Grow?



- Mass Evolution
  - max ~1g
  - Bouncing inhibits further growth
- Porosity Evolution
  - very fluffy aggregates after ~1000 years
  - Bouncing compacts aggregates

Zsom et al., 2010

Improvement of Monte Carlo Method



Zsom et al., 2010

Zsom et al., in press, A&A

- Collision types are much more diverse due to vertical mixing
- Fragmentation occurs, and the size distribution gets even wider
- Production of micrometer-sized grains in the disk atmosphere
- No final breakthrough through the bouncing barrier with the full, complex model

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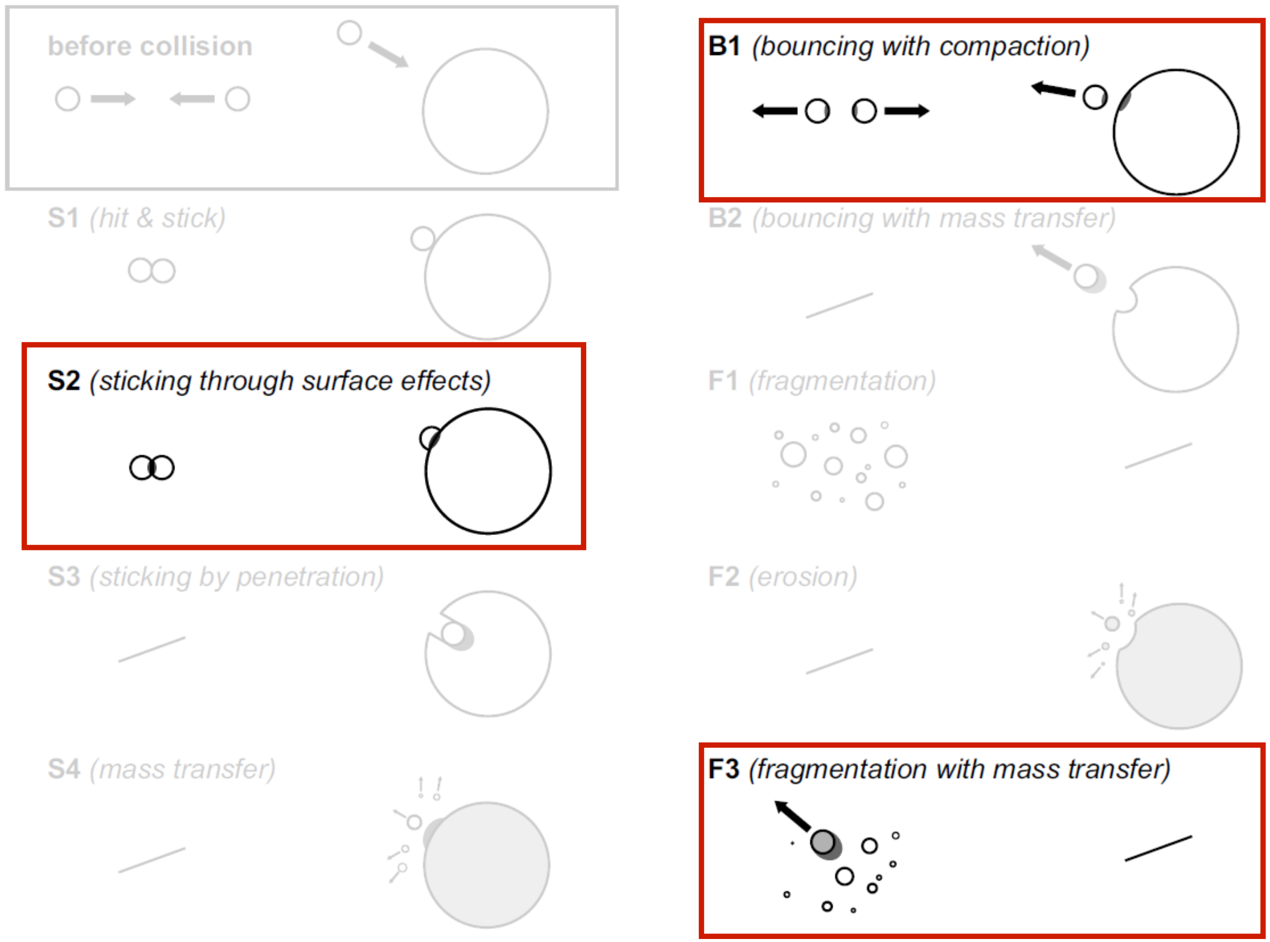

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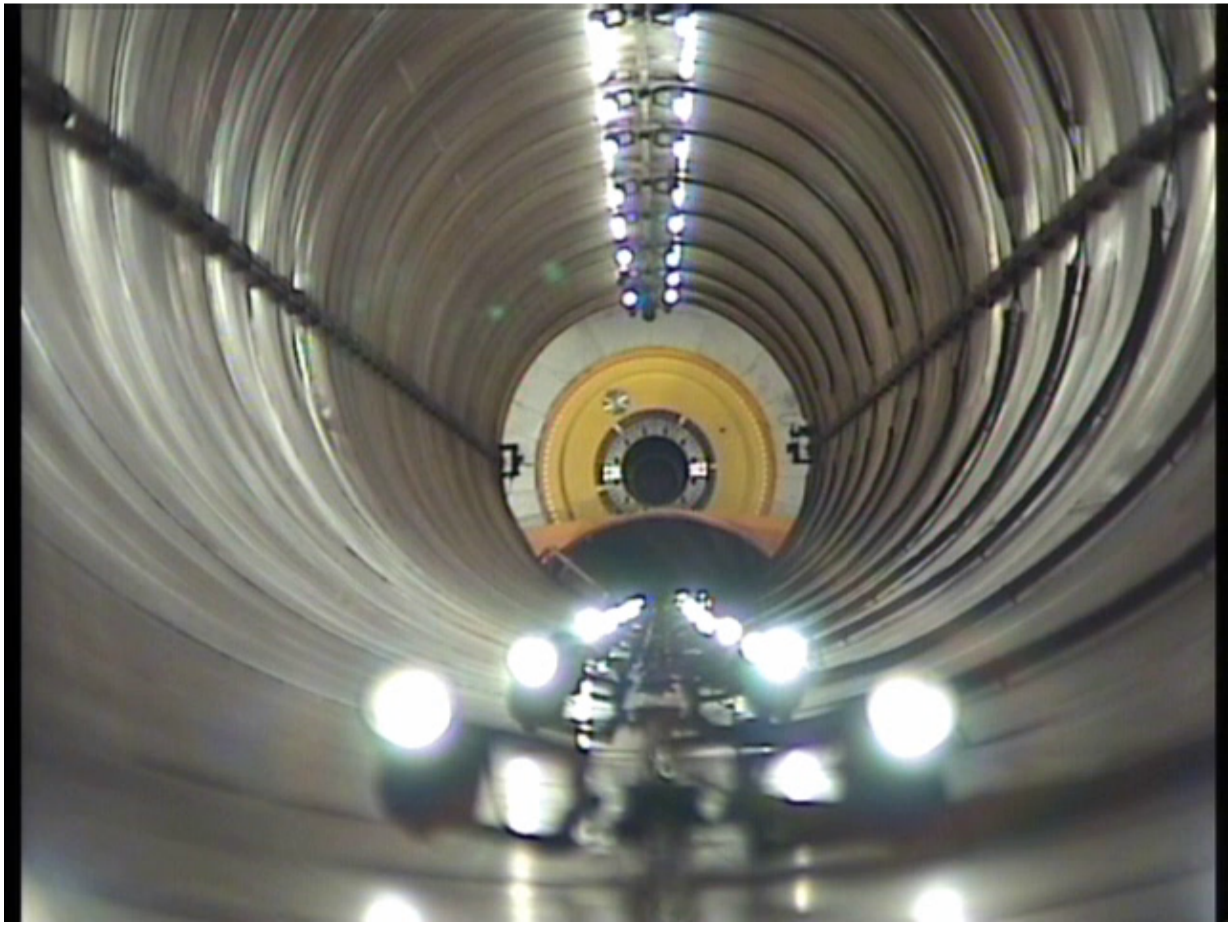
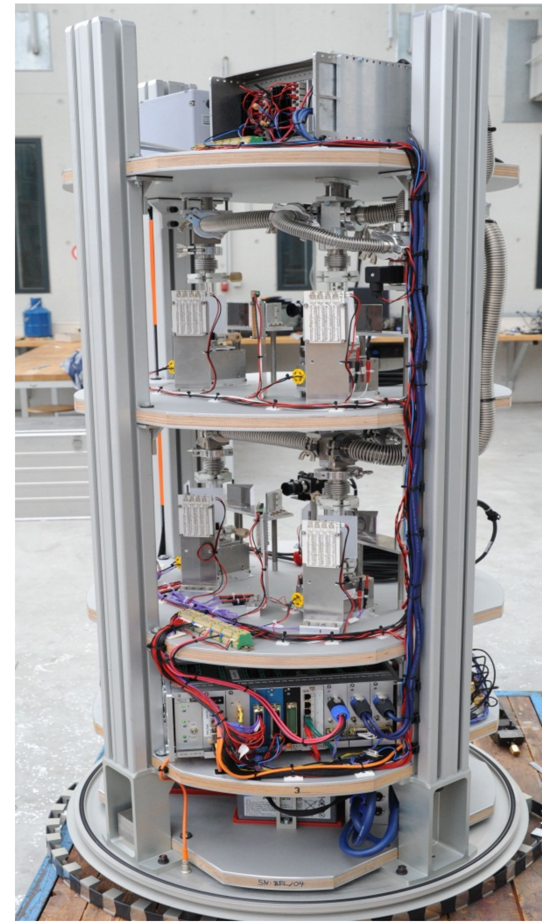
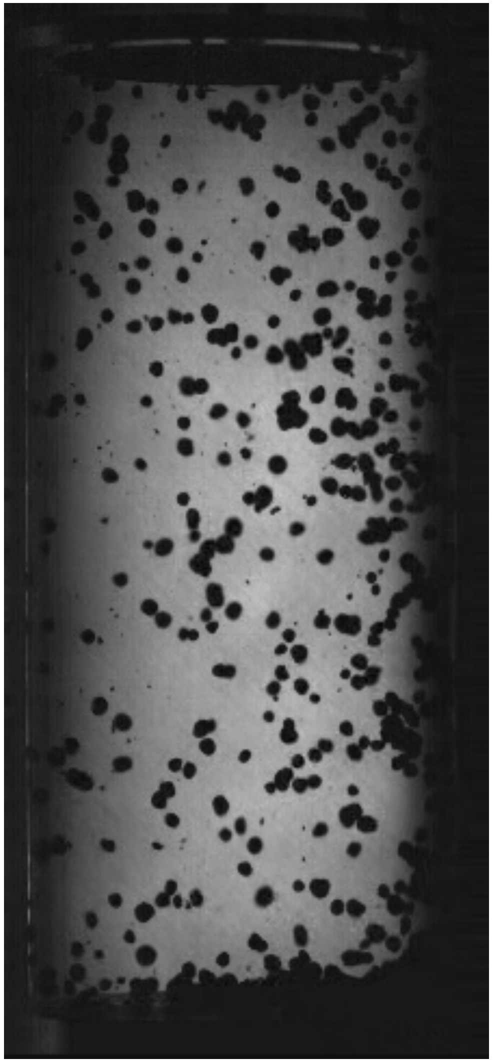
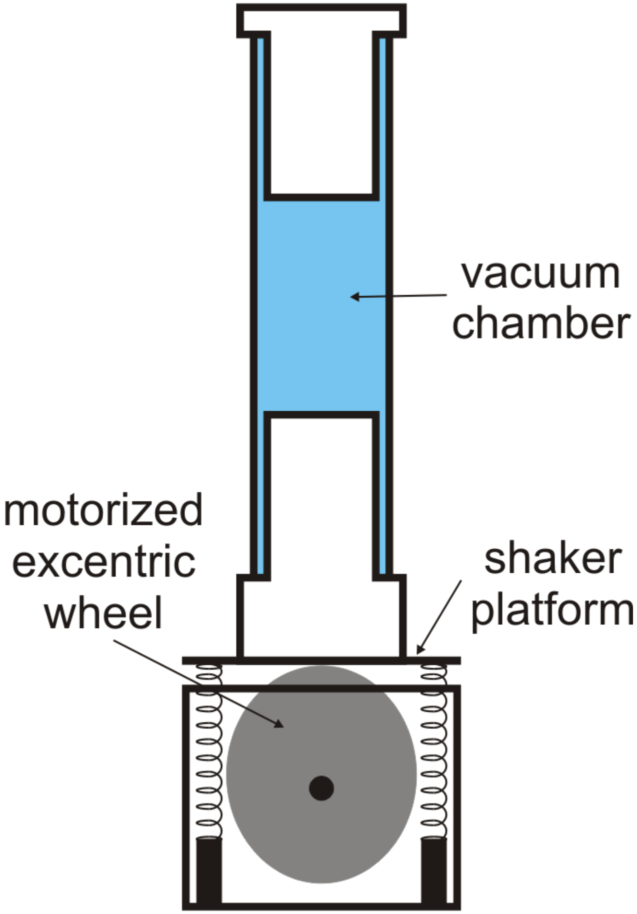
Drop Tower Bremen





Collisional Outcomes

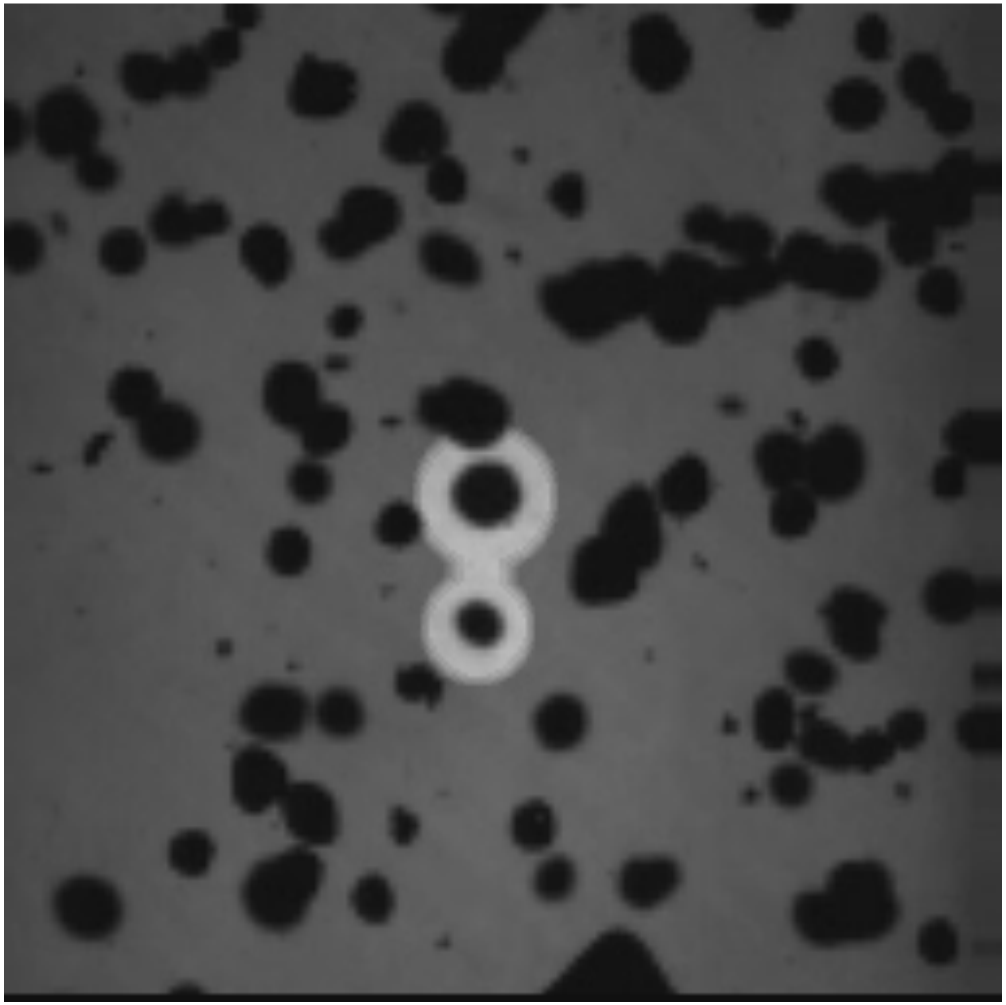




- Microgravity experiment (drop tower, suborbital flight)
- Particle diameter: 0.5-1.5 mm
- Initial velocity ~0.1m/s
- Collisional cooling down to mm/s

Weidling et al., subm., Icarus

Bouncing



Bouncing collision

v = 62 mm/s

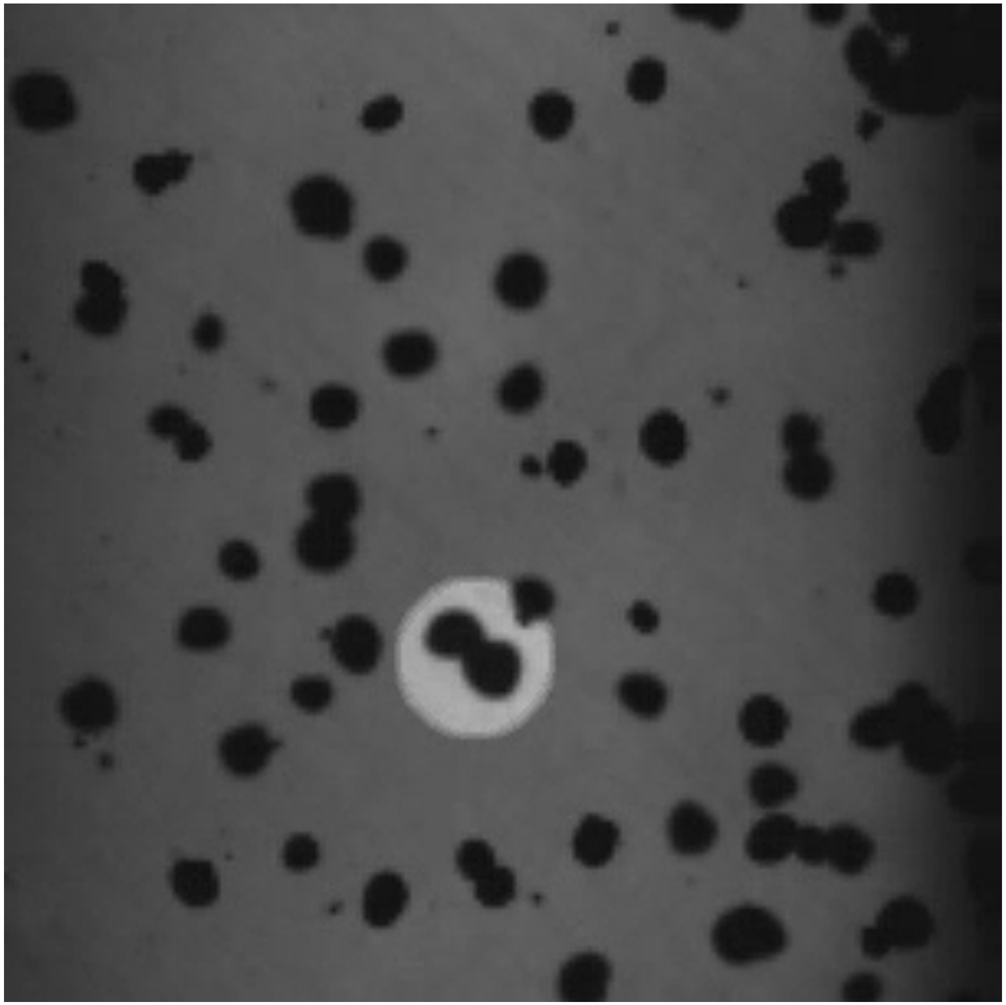
particle size:
0.5-1.5 mm

particle diameter: 1 mm
filling factor: 40%

103 analyzed collisions:
- 7x sticking
- 95x bouncing
- 1x fragmentation

Weidling et al., subm., Icarus

Sticking



Sticking collision

v = 9 mm/s

particle size:
0.5-1.5 mm

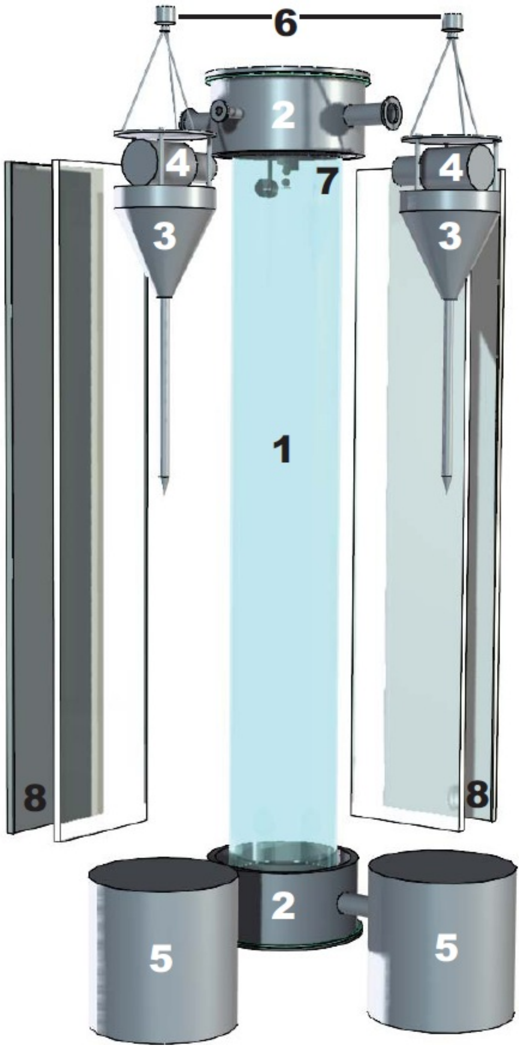
particle diameter: 1 mm
filling factor: 40%

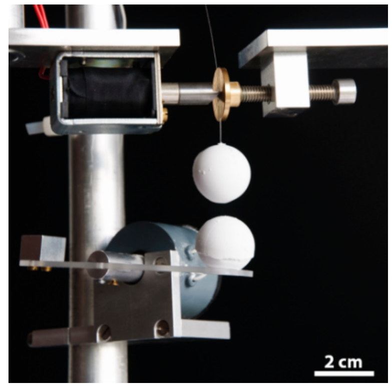
<u>103 analyzed collisions:</u>

- 7x sticking
- 95x bouncing
- 1x fragmentation

Weidling et al., subm., Icarus

Laboratory Drop Tower

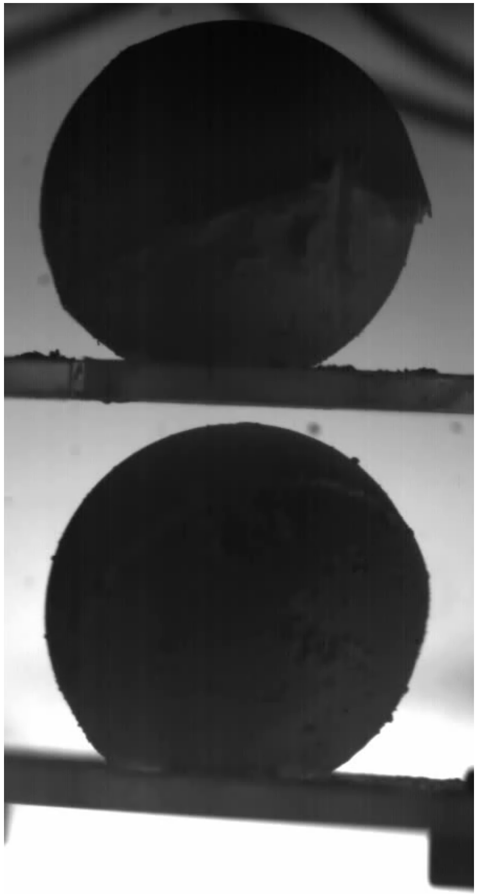




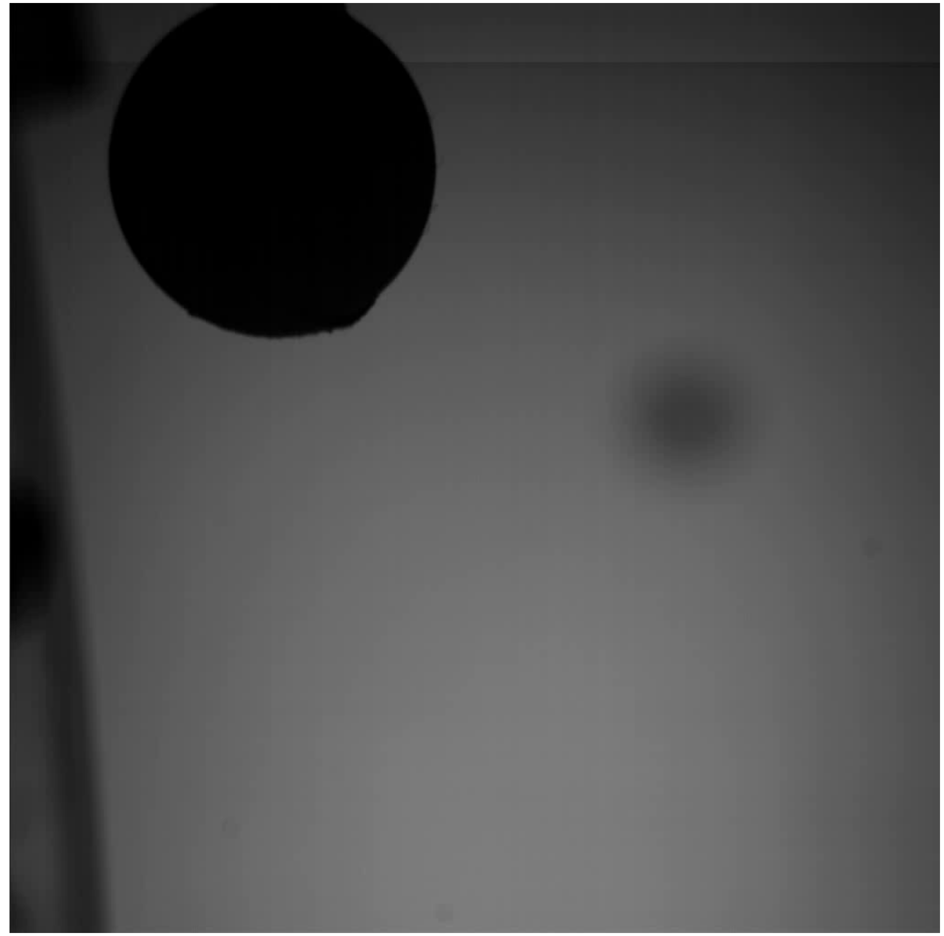
- Laboratory drop tower
- Two aggregates collide in free fall
- Two falling cameras, 1.5 m drop height
- Velocities from 1 cm/s to 3 m/s

Beitz et al., 2011

Fragmentation Threshold



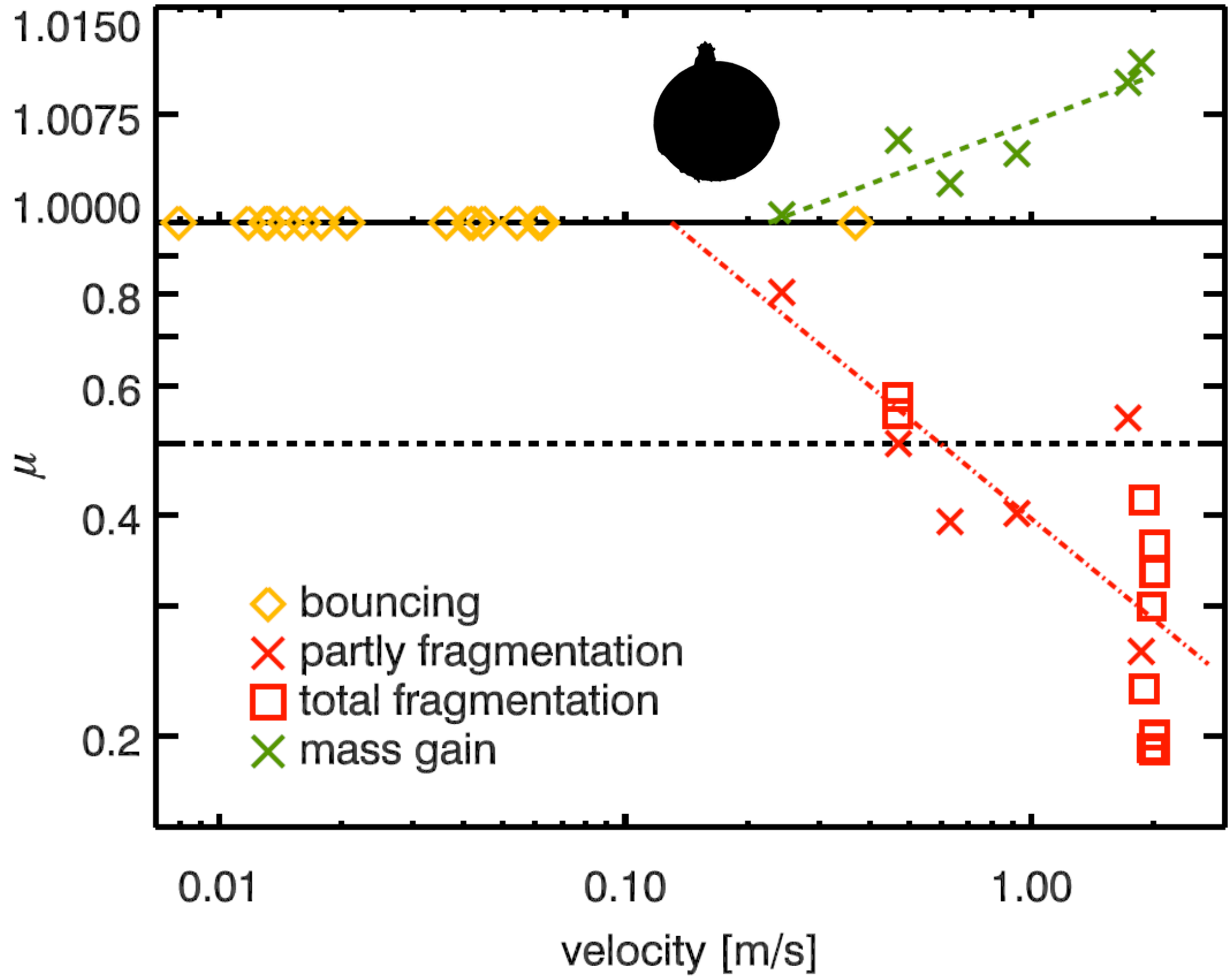
2cm diameter, 50% filling factor, velocity: 10 mm/s



2cm diameter, 50% filling factor, velocity: 1.8 m/s

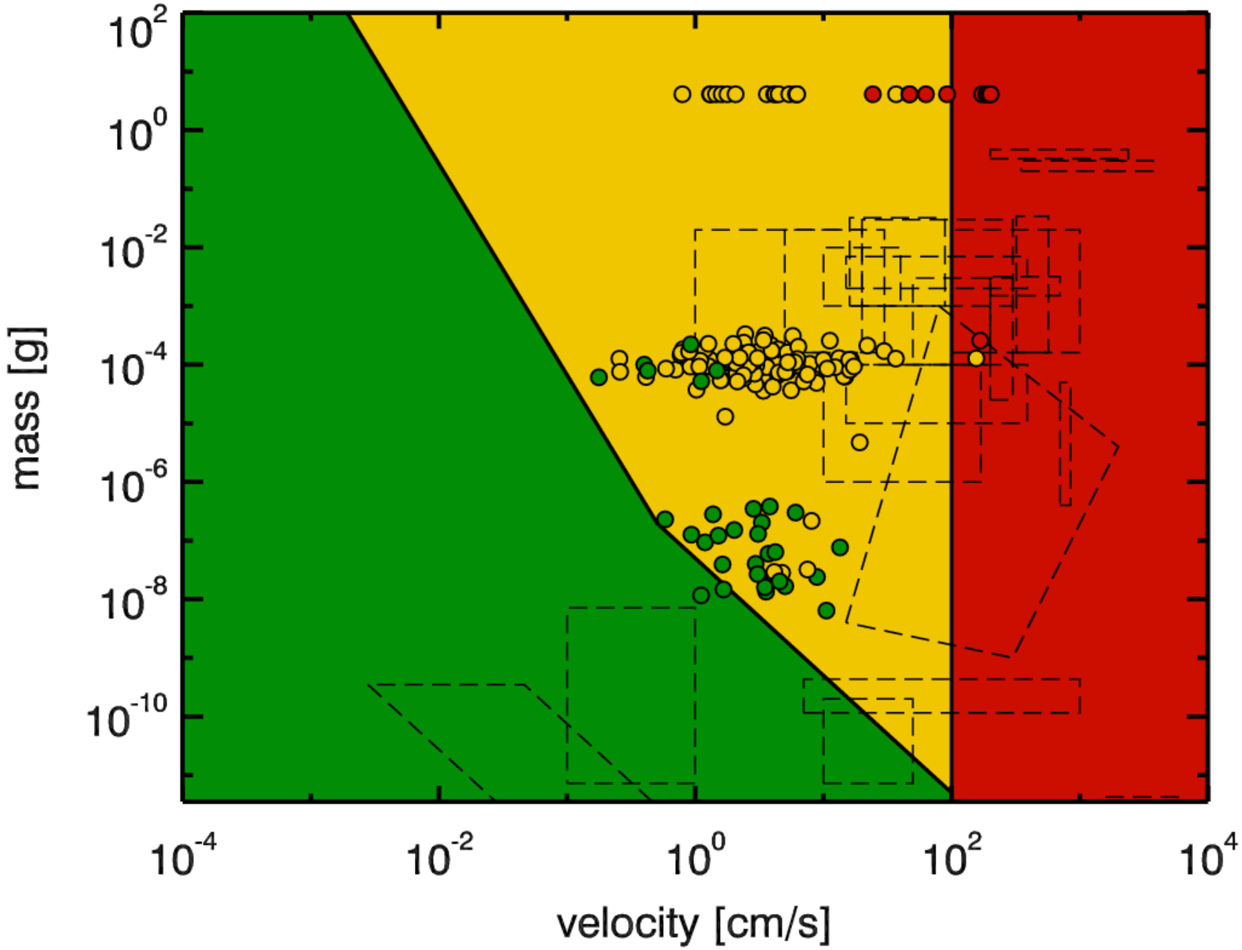
Collisional Outcomes

- **bouncing** for v < 20 cm/s
- **fragmentation** with mass transfer for v > 20 cm/s



Beitz et al., 2011

Update on the Collision Model



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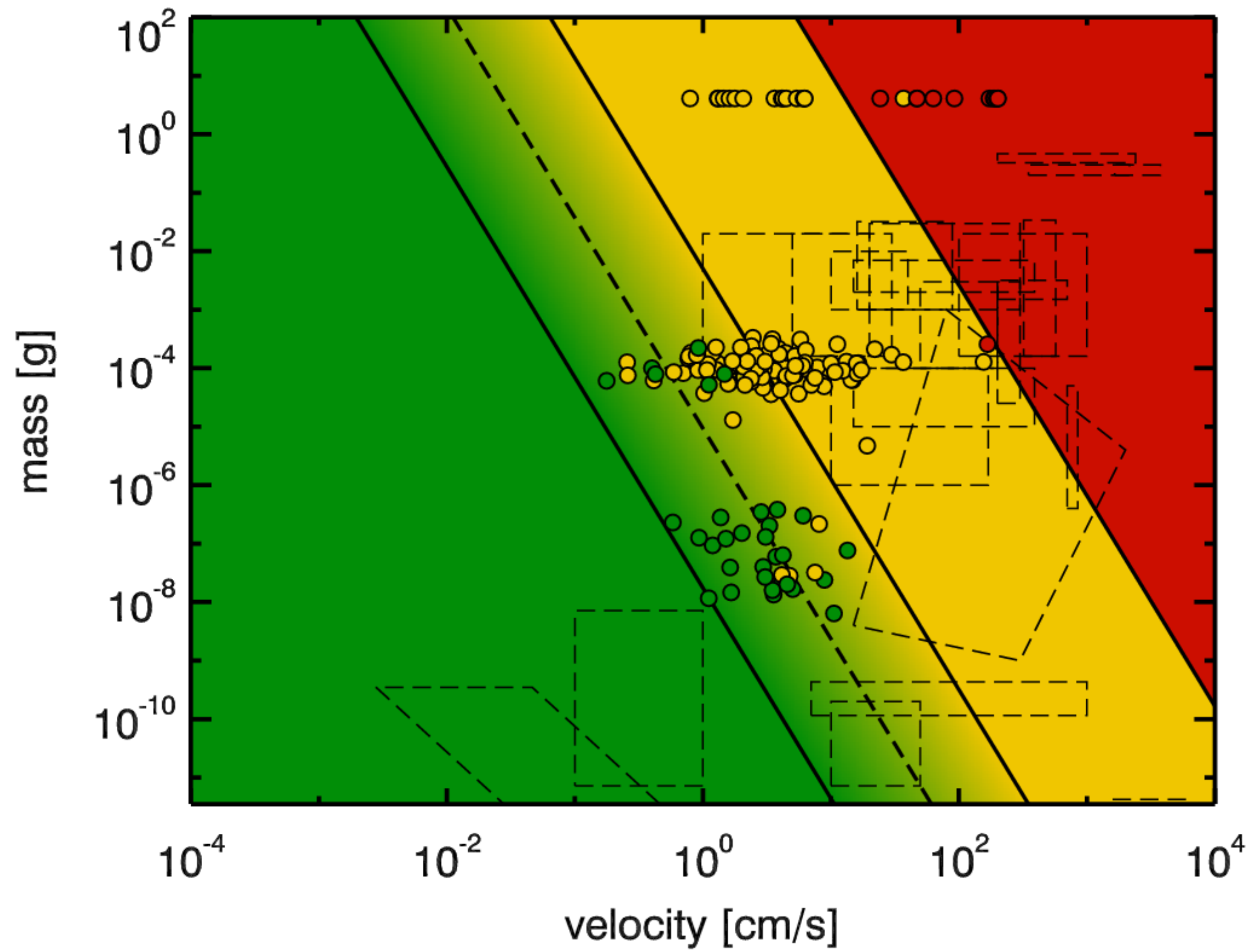

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Thank you for your attention!

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I want to thank René Weidling, Eike Beitz, and Stefan Kothe for providing their unpublished data.

Additional information on the presented model can be found in Güttler et al. (2010, A&A) and Zsom et al. (2010, A&A).

Recent laboratory results are published by Kothe et al. (2010, ApJ), Beitz et al. (2011, ApJ), and Weidling et al. (2011, subm.).