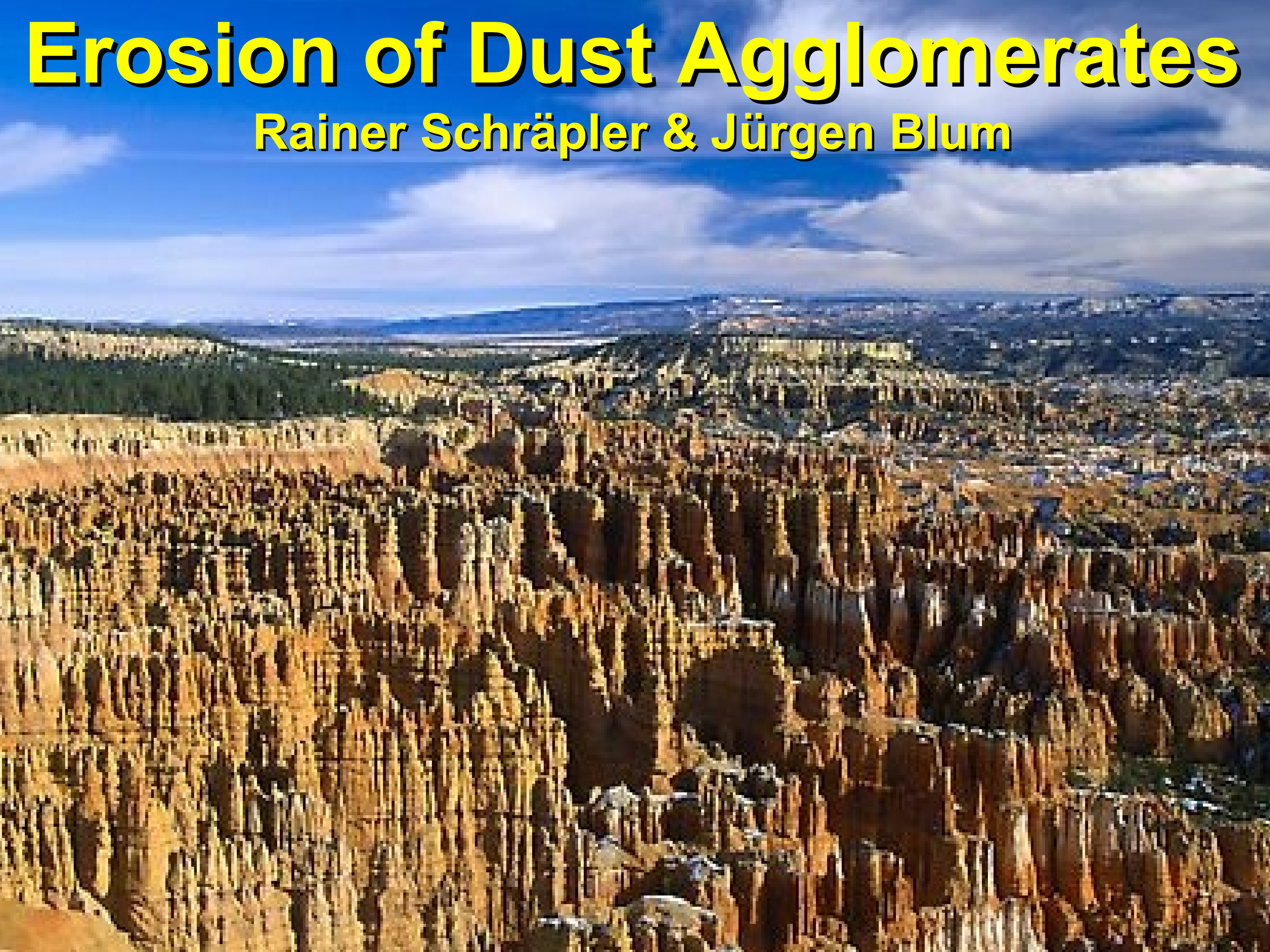
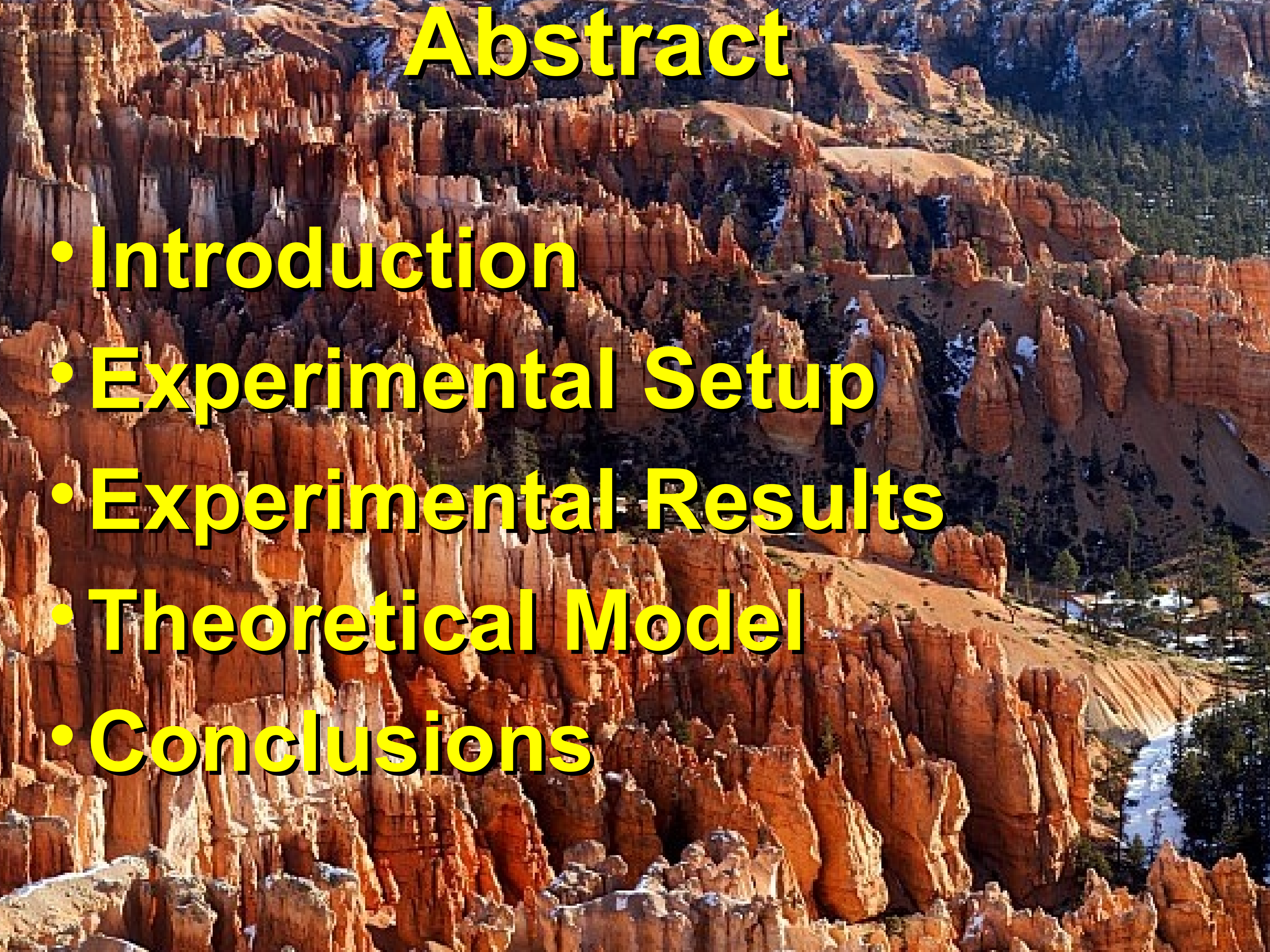
Erosion of Dust Agglomerates

Rainer Schräpler & Jürgen Blum



Abstract



- Introduction
- Experimental Setup
- Experimental Results
- Theoretical Model
- Conclusions

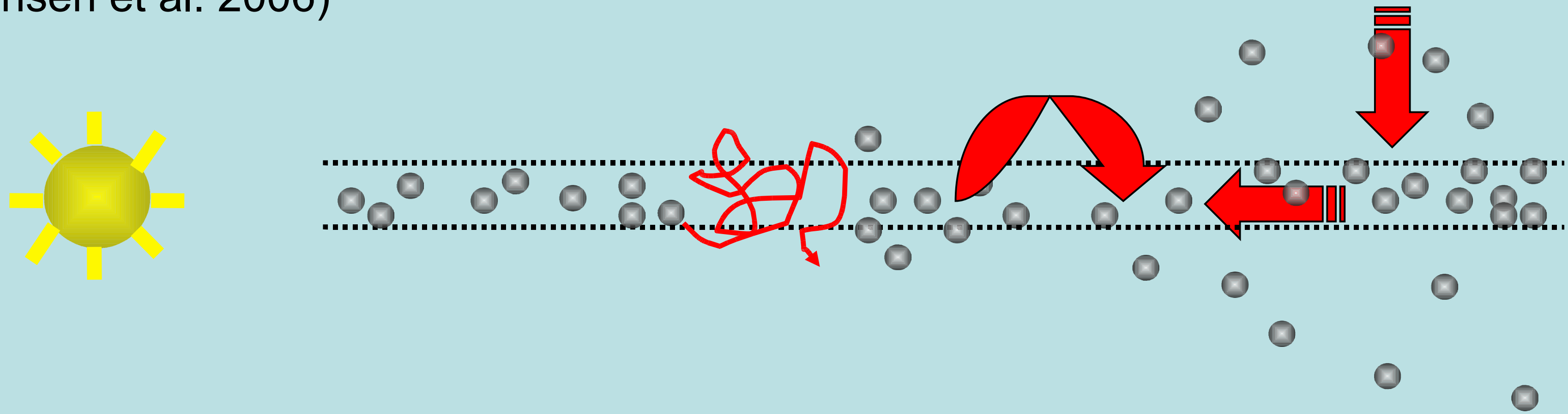
Introduction

Brownian motion (Weidenschilling 1984)

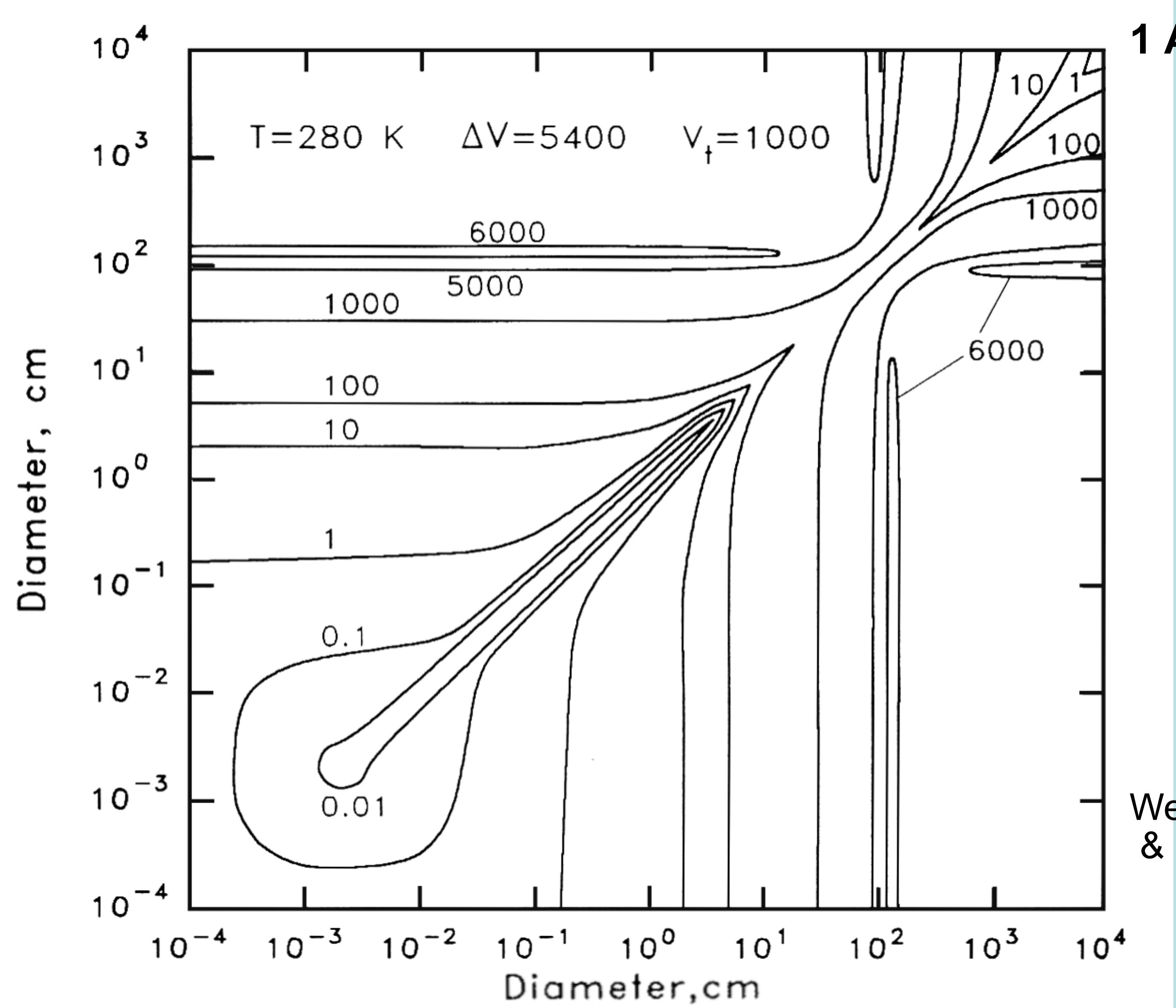
Vertical sedimentation, radial drift, azimuthal velocity differences (Weidenschilling 1984),

Strong outward directed winds over dust subdisks.
(Cuzzi 1993)

Gas turbulence (magneto-rotational instability, shear instability, gravitational instability)
(Weidenschilling 1980; Sekiya 1998 Balbus & Hawley 1991; Schräpler & Henning 2004; Johansen et al. 2006)



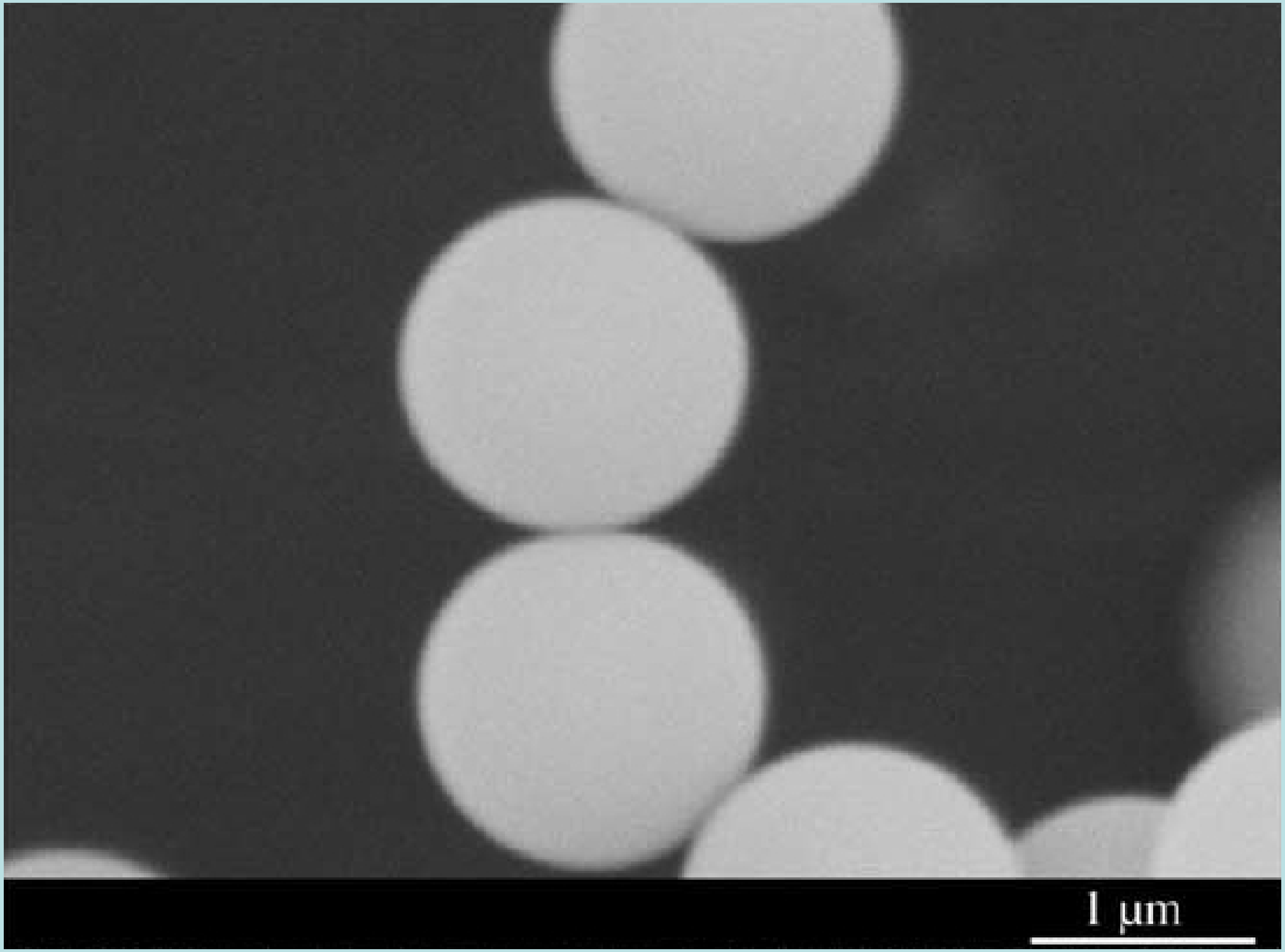
A Model for the Collision Velocities Between Protoplanetary Dust Grains



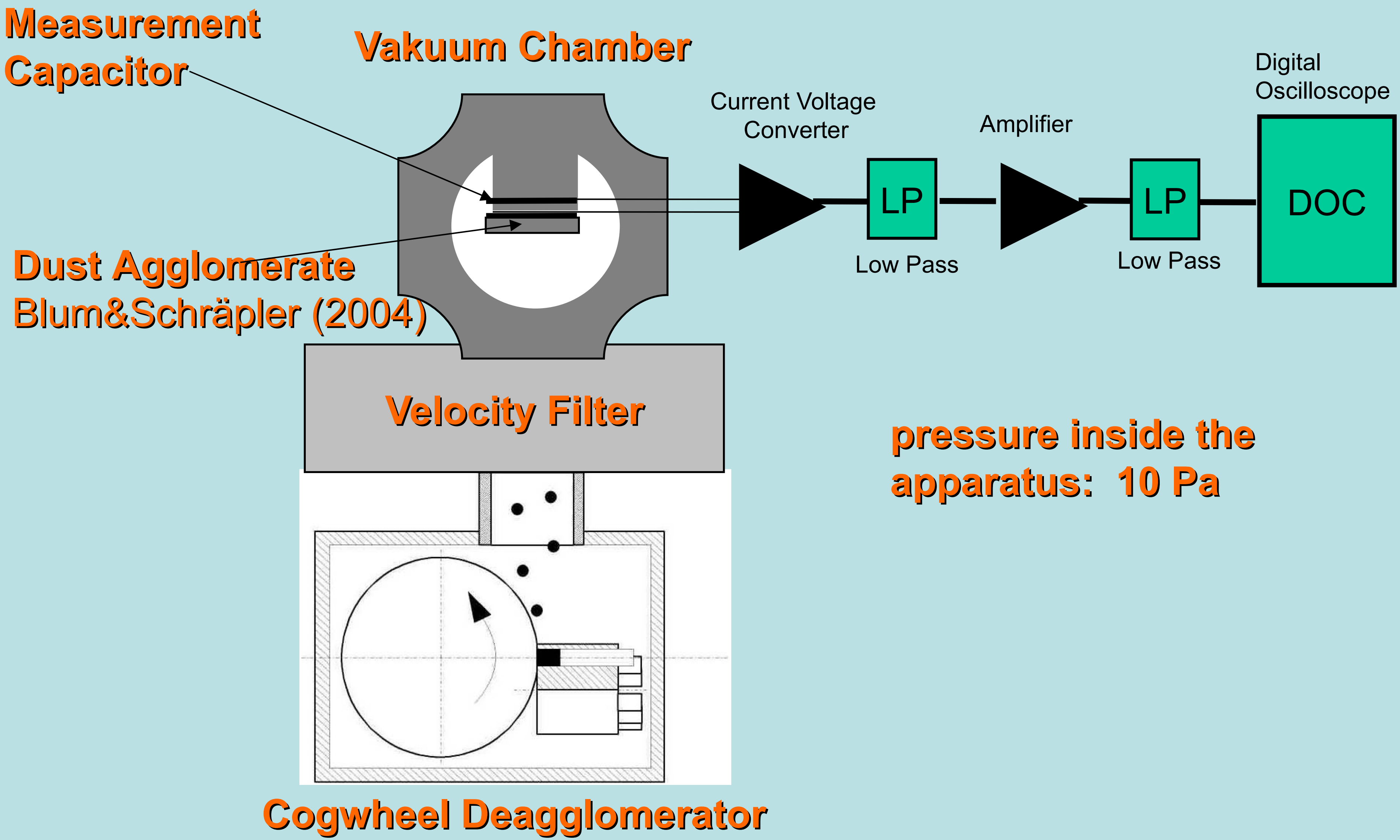
1 AU

Weidenschilling & Cuzzi 1993

Particles Used in Our Experiments



Experimental Setup



Measurement Capacitor

Vakuum Chamber

Current Voltage Converter

Amplifier

Digital Oscilloscope

LP

Low Pass

LP

Low Pass

DOC

Dust Agglomerate

Blum&Schräpler (2004)

Velocity Filter

Cogwheel Deagglomerator

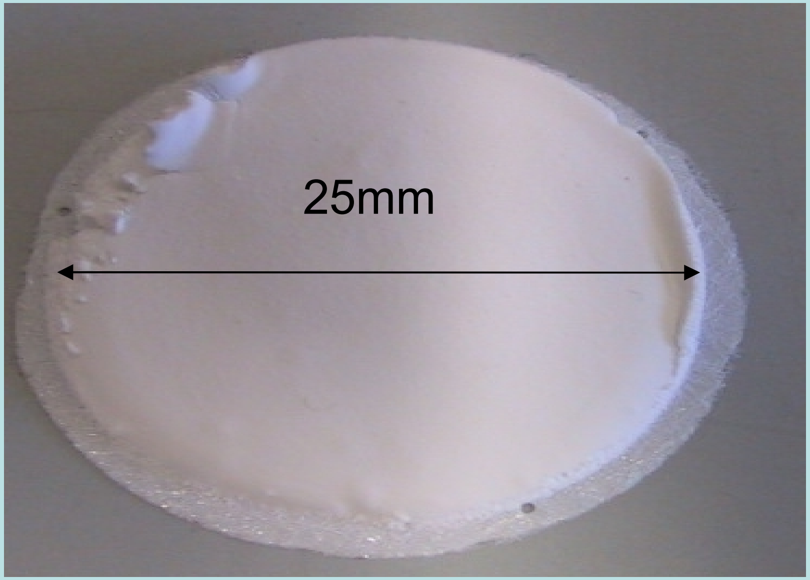
pressure inside the apparatus: 10 Pa

Laboratory Setup

Measurement method

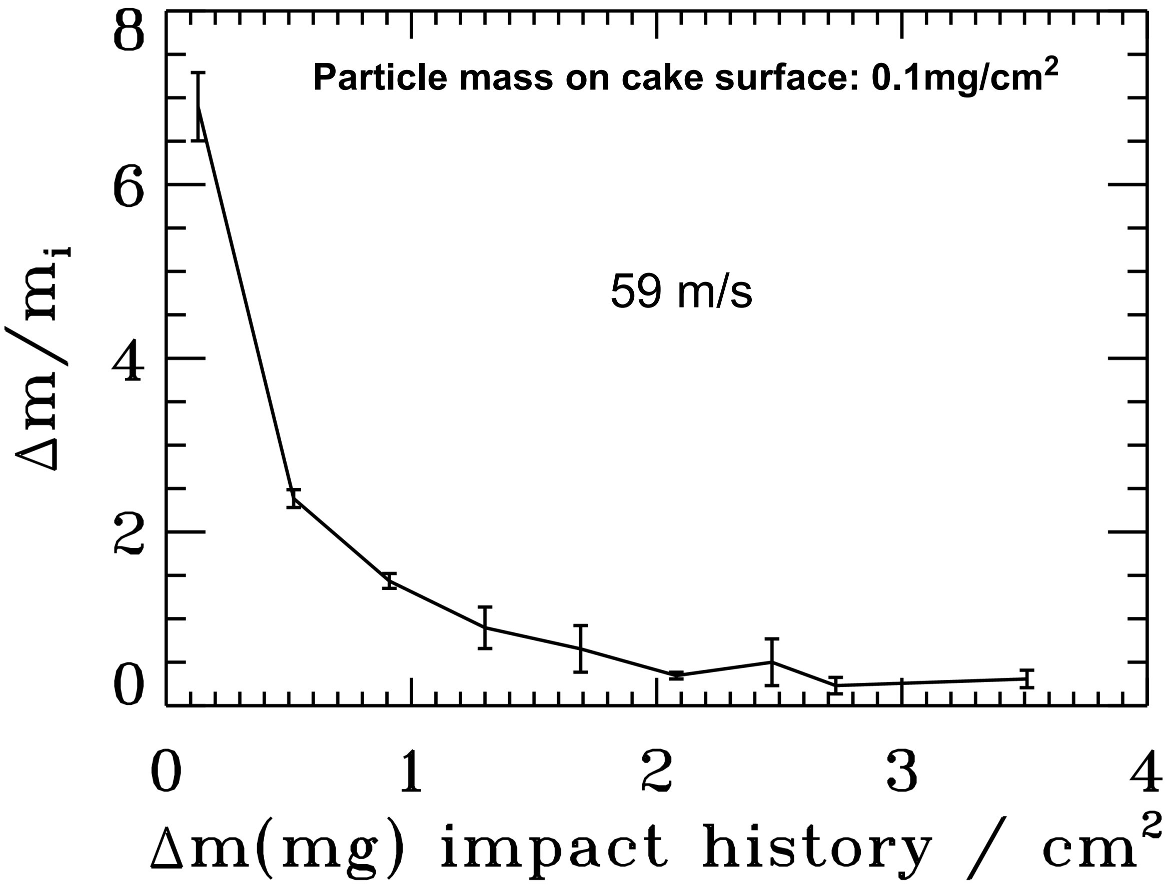
- Measurment of the particle mass arriving at a greased target
- Measurement of the mass change of the agglomerate target

Agglomerate before imapact

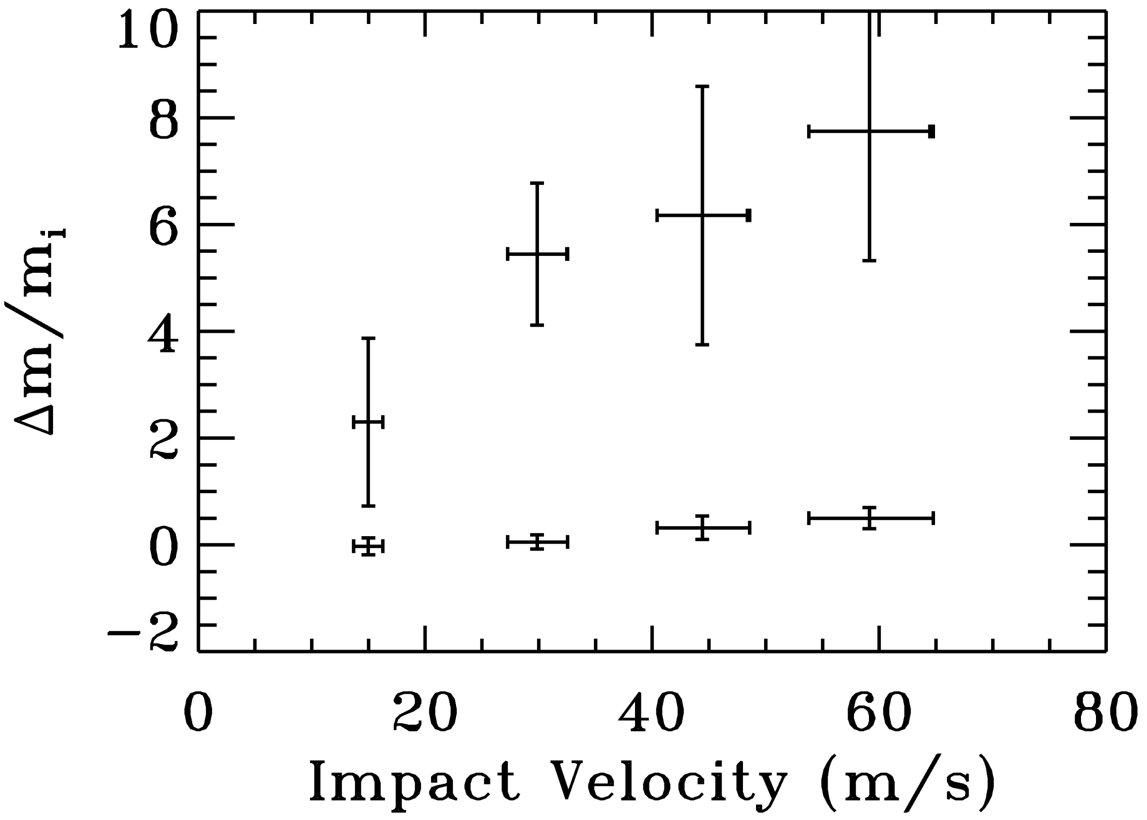


Agglomerate after impact with µm spheres

Experimental Results



Erosion versus impact velocity



Numerical Model of Konstadopoulos (2000)

- High speed impacts increase the filling factor of an agglomerate and therefore the number of particle - particle contacts n (coordination number)

- maximum coordination number is an gaussian distribution with its maximum at 6 and its full width halve maximum of 4 (ff=0.6)

- A particle bond in the agglomerate can be described by an effective mass term
  (found by numerical simulations)

Impact energy needed to release an “effective” particle

Effective mass: $m_{eff} = m\,(1 + C\,n)$ (Konstandopoulos 2000)

n: number of contacts to neighbour particles (coordination number)
C:dimensionless rigidity parameter **[1,infinity]**

Energy transfered to an effective particle:

$E_{eff}=E_{imp}4(1+C\,n)(2+C\,n)^{-2}$ (momentum law)

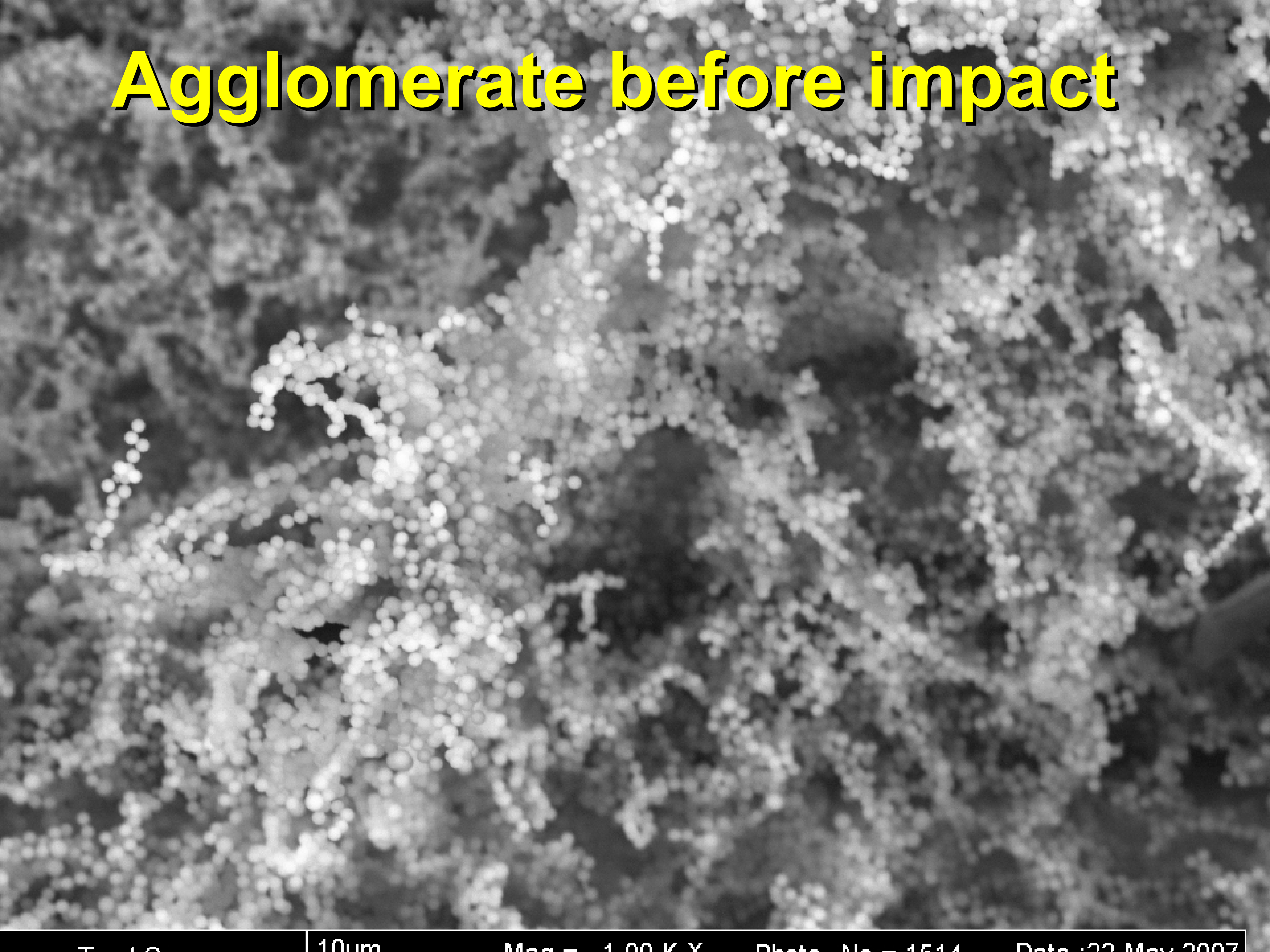
Energy needed to release a particle from the agglomerate

$E_{release}=E_{contact}n$; $E_{\,contact}=2$ E-15 J (Heim & Blum 1999)

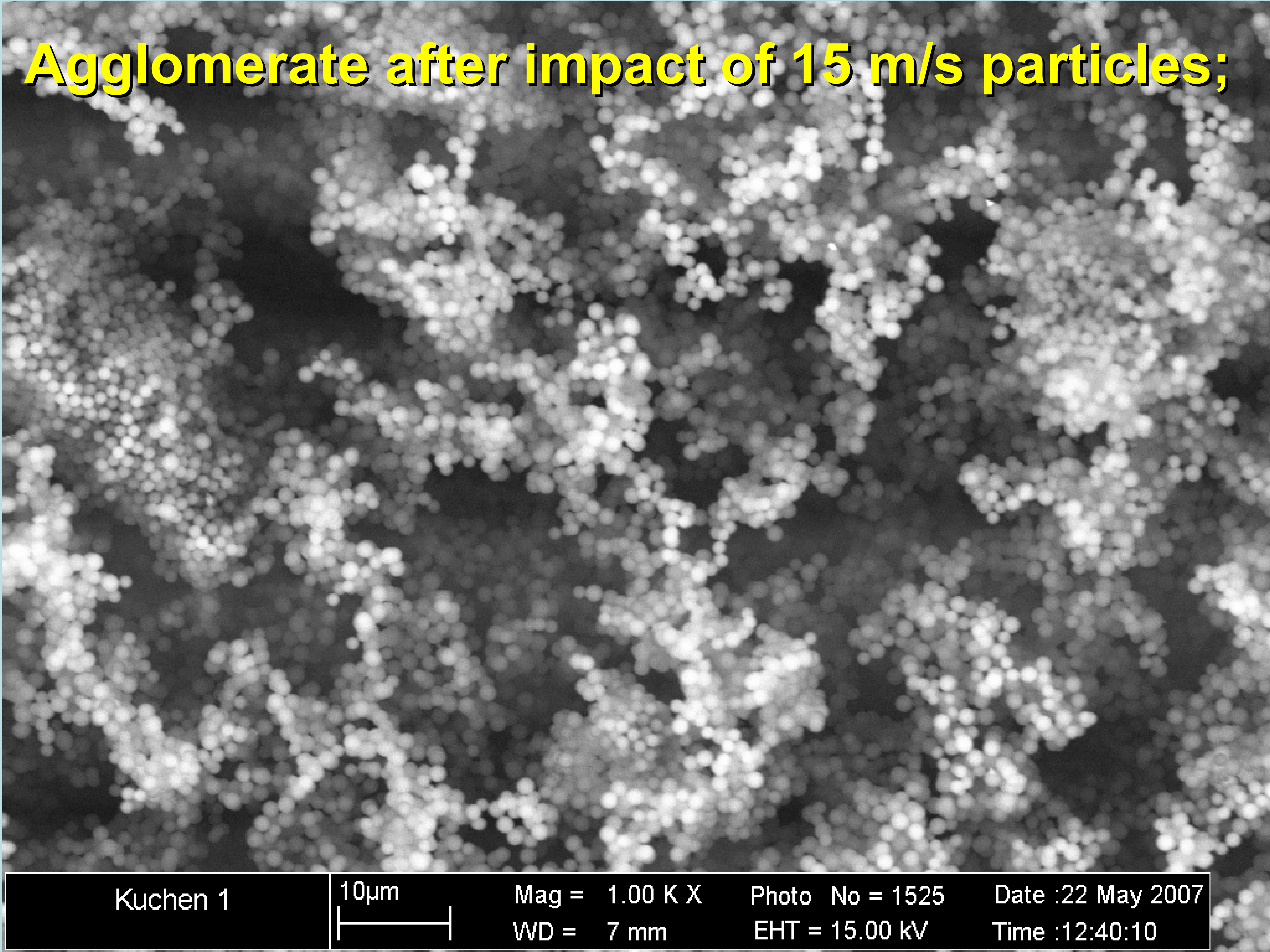
The agglomerate is passivated if the effective energy transferred by an impact is lower than the release energy

Koordination number on the surface: **Agglomerate: n~1.6;**
passivated Agglomerate (60m/s) n~5
Ratio of needed energy (5/1.6)^2 ~ 10

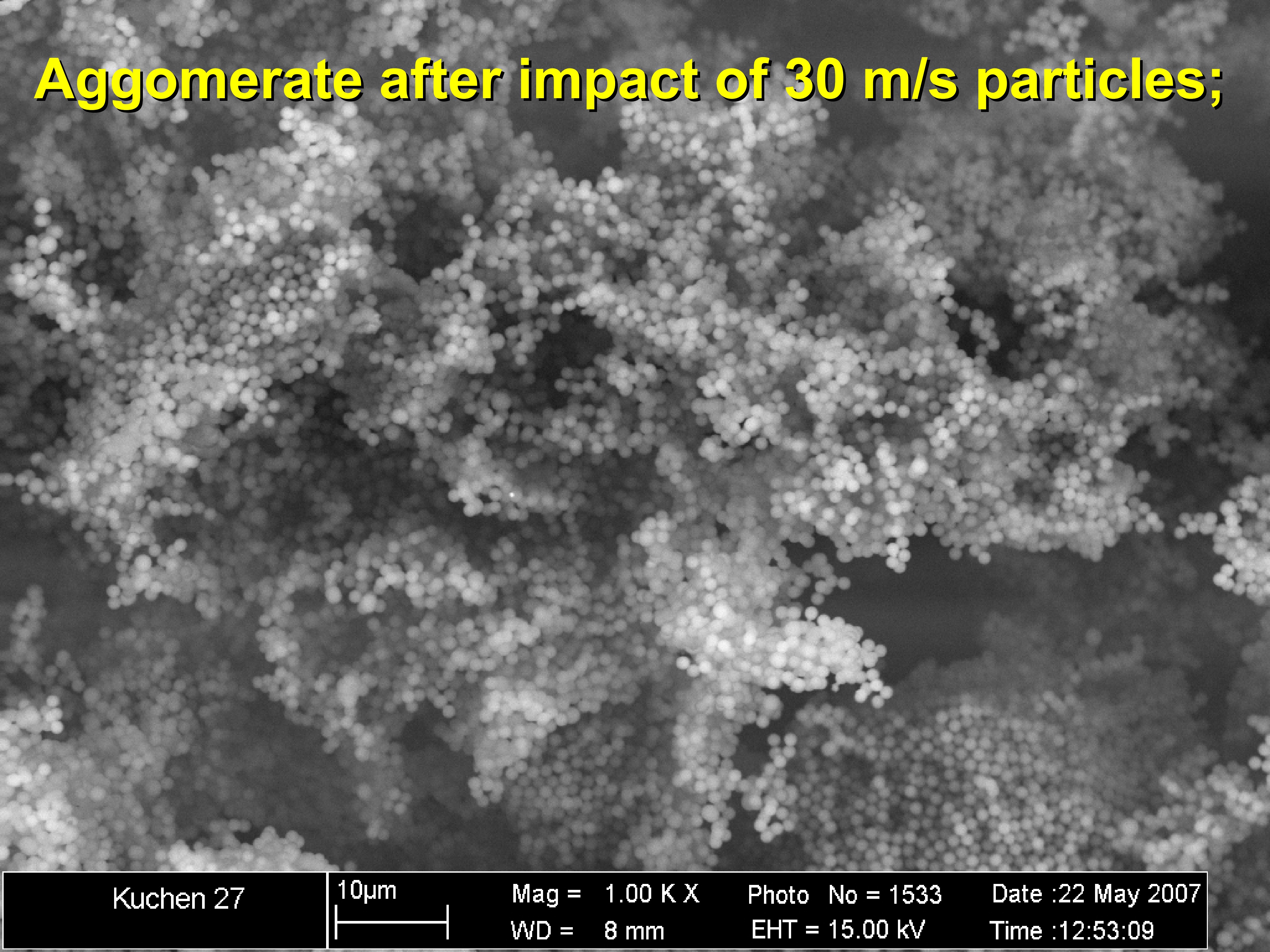
Agglomerate before impact



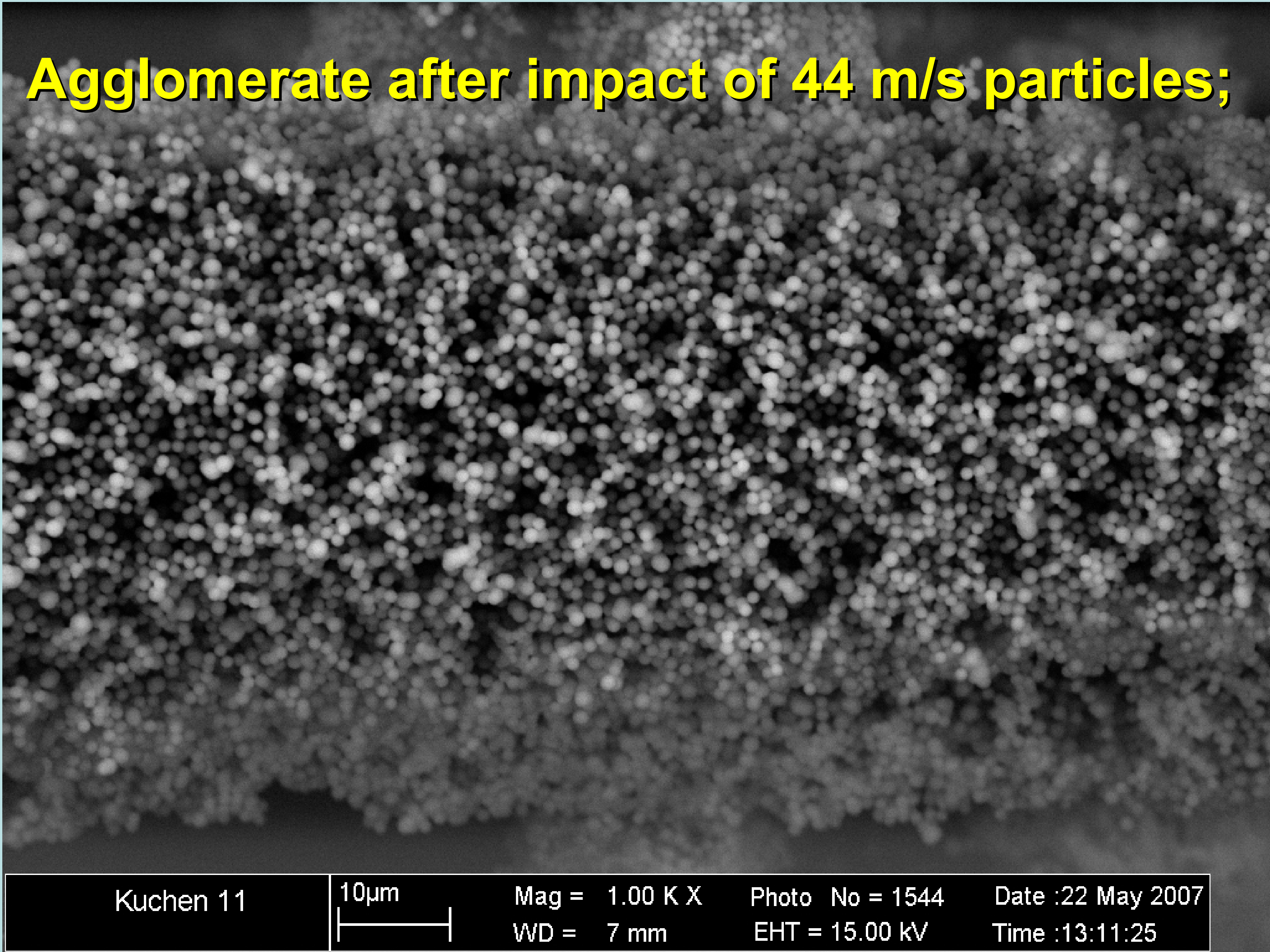
Agglomerate after impact of 15 m/s particles;



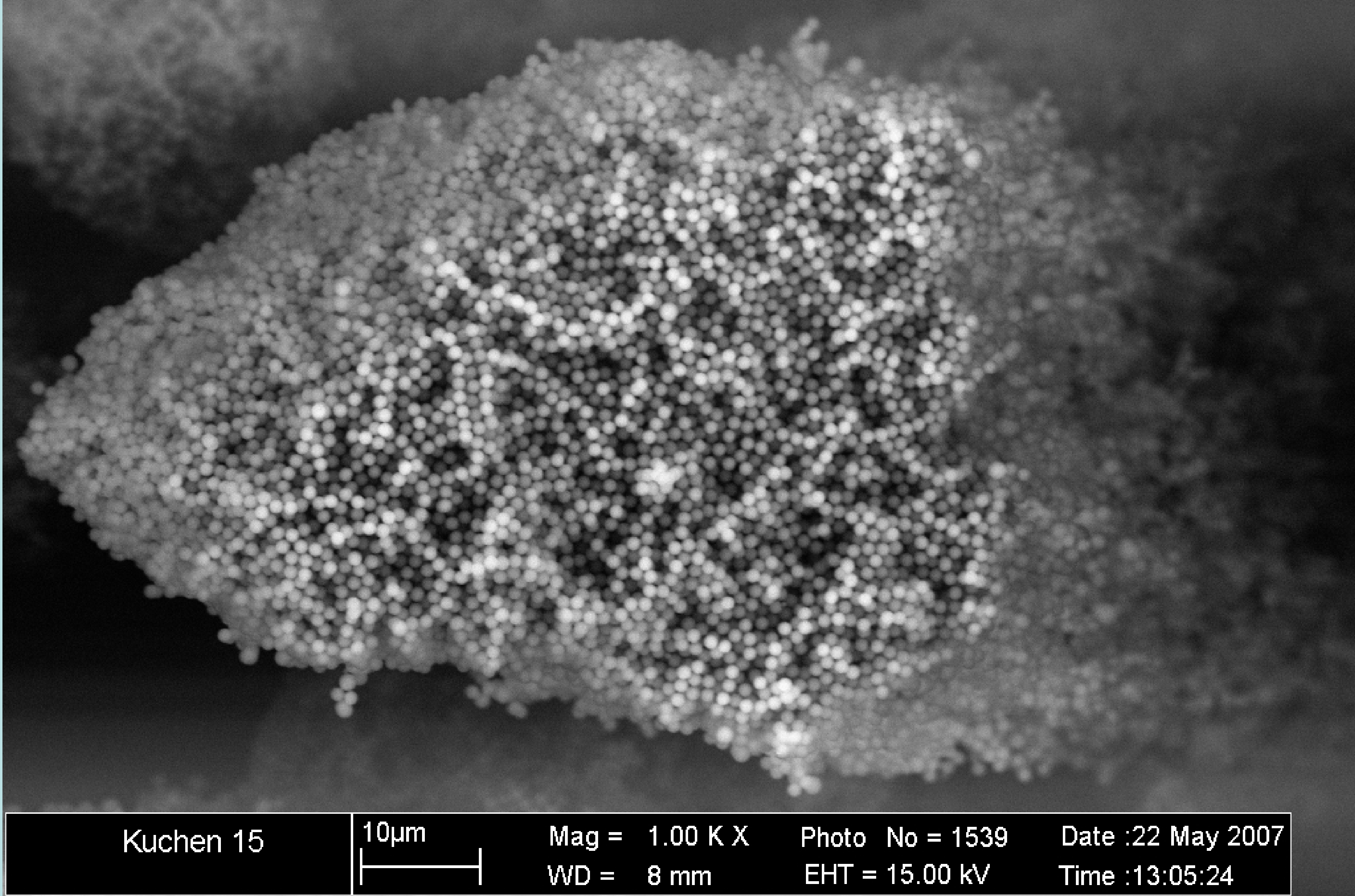
Aggomerate after impact of 30 m/s particles;



Agglomerate after impact of 44 m/s particles;



Agglomerate after impact of 59 m/s particles;

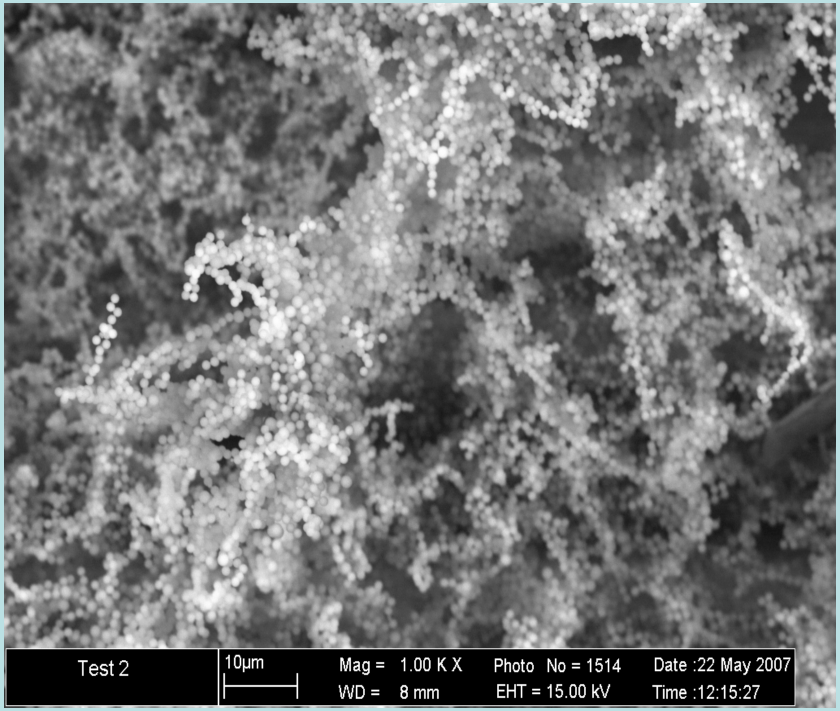


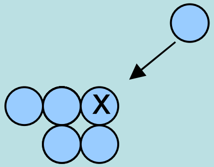
Model (first part)

effective mass $m_{eff} = m\,(1 + C\,n)$ (Konstandopoulos 2000)

n: coordination number
C:rigidity parameter **[1,infty] chosen:1 (fluffy material)**

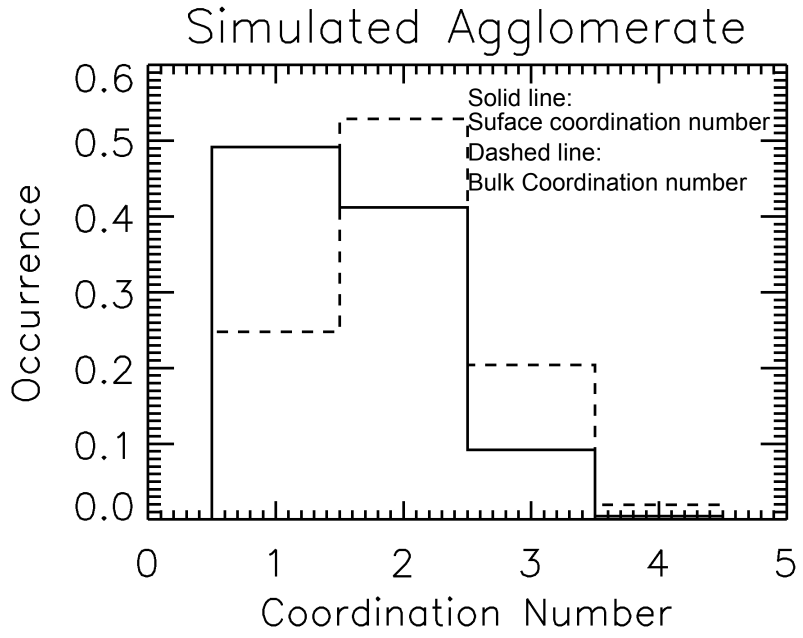
kinetic energy loss per impact 20x binding energy

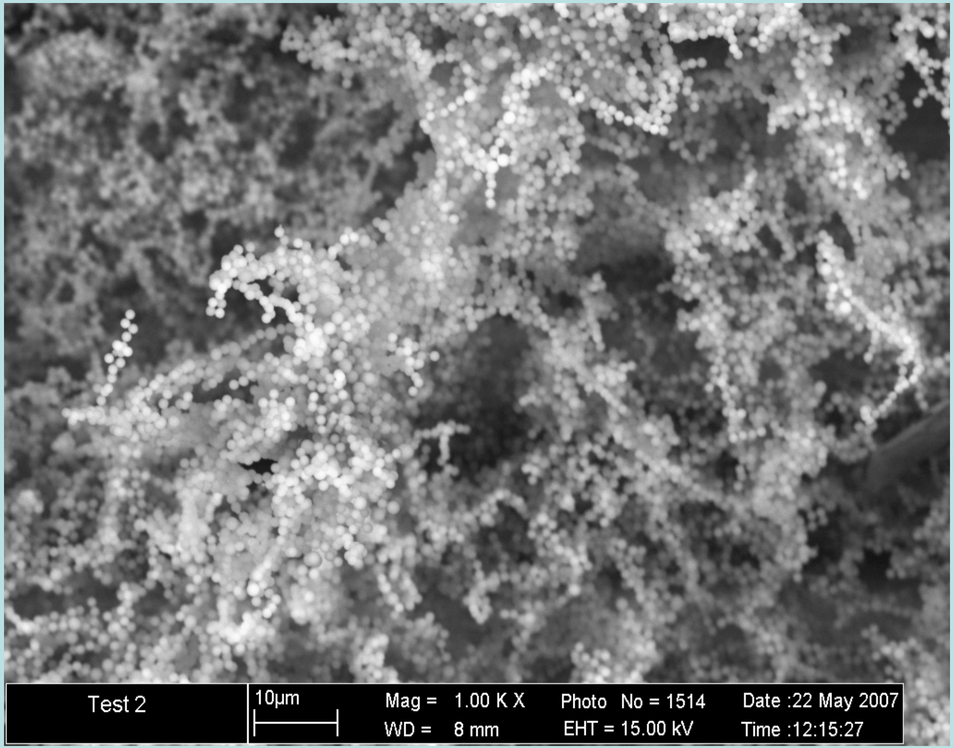




Post impact energy and momentum for X-particle and impactor are known by momentum and energy laws.

The X-particle is ejected if its post impact kinetic energy is larger than its binding energy

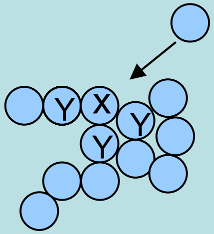




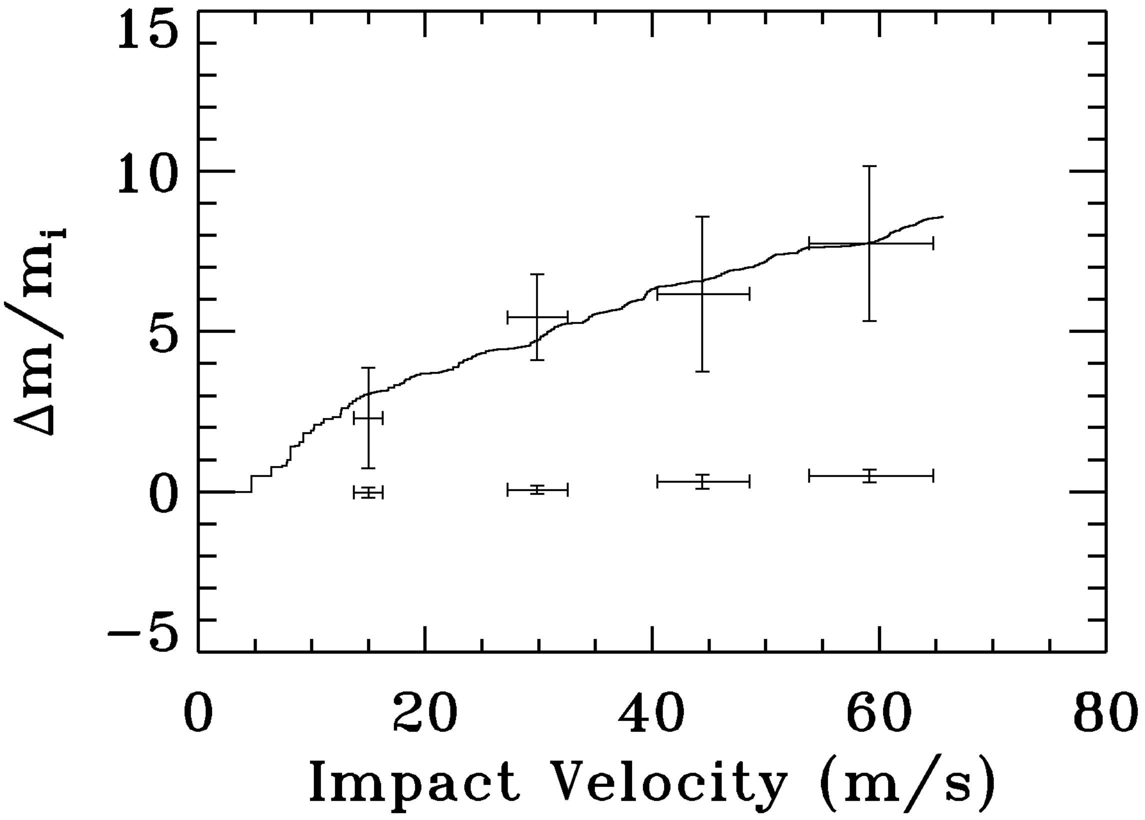
- The impact is calculated for all possible coordination numbers.
- The results are multiplied with the occurence of the respecive coordination number and accumulated.
- After each possible impact the impactor is reflected and can impact at a further agglomerate particle
  - with a probability of 0.65 (escape cone angle 95°) corresponding to the surface structure of the agglomerate
  - in average a particle impacts 2.8 times (geometrical series)

Model (second part):
Strikout of several particles per impact

- The X particle impacts with its given momentum at the Y-particles
- The momentum is distributed reciprocally proportional to the effective masses of the Y-particles
- If $E_{kin} > n*E_{contact}$ the Y-particle will be ejected.
  The Y-particle is transformed to a X-Particle (recursion)



- All possible combinations of effective masses and numbers of Y-particles in contact with the X-particle are calculated, multiplied with the probability of their occurance and added.
- The ejected X- and Y- particles will again impact at the agglomerate with a probability of 0.65.
- At high energies they release other particles
  At medium energies they are reflected

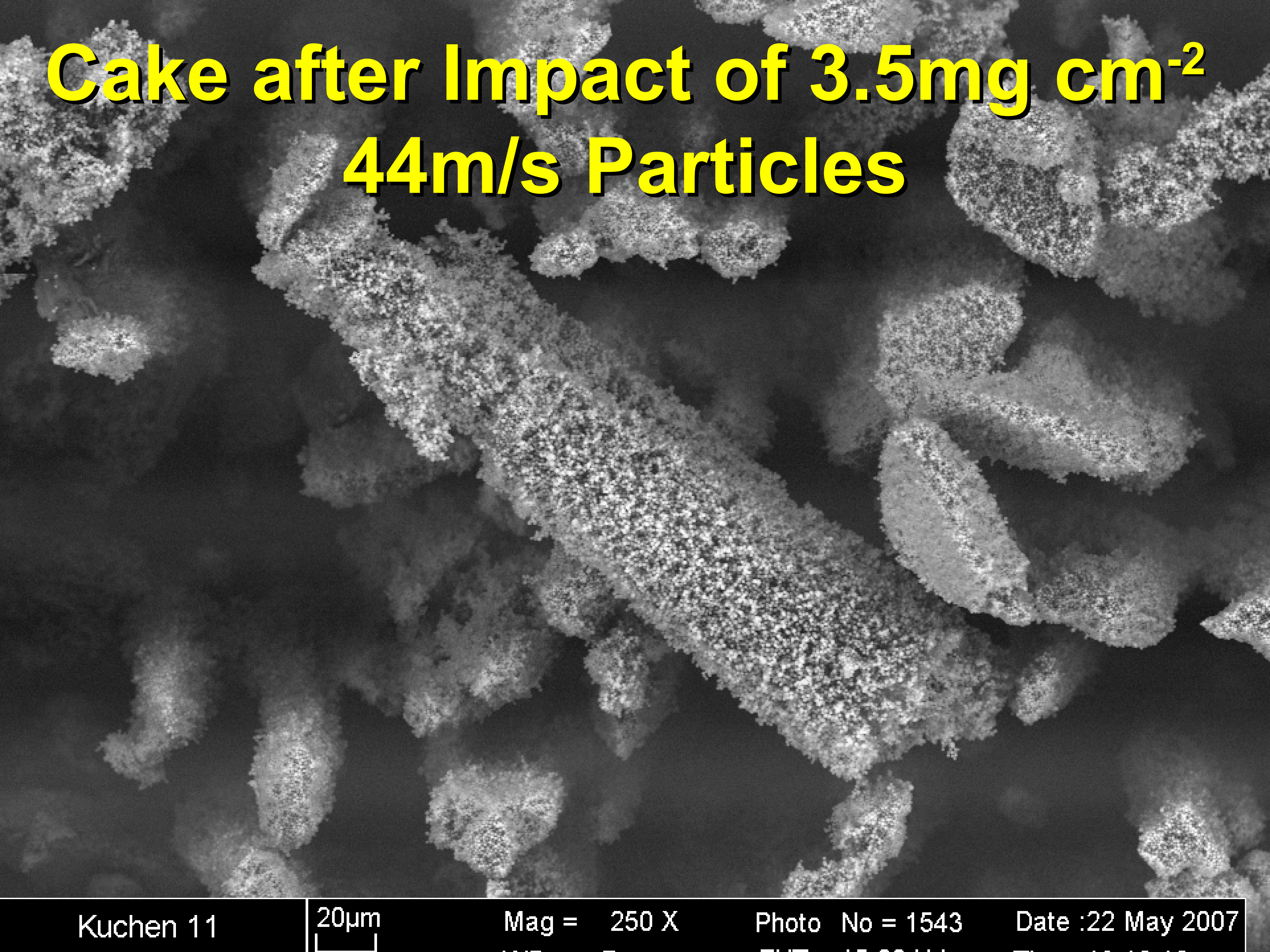

15
10
5
0
−5
0
20
40
60
80
Δm/m_i
Impact Velocity (m/s)

Conclusion

- solar nebula agglomerates faster than 35m/s are eroded by micron sized grains and are a source of micron sized particles

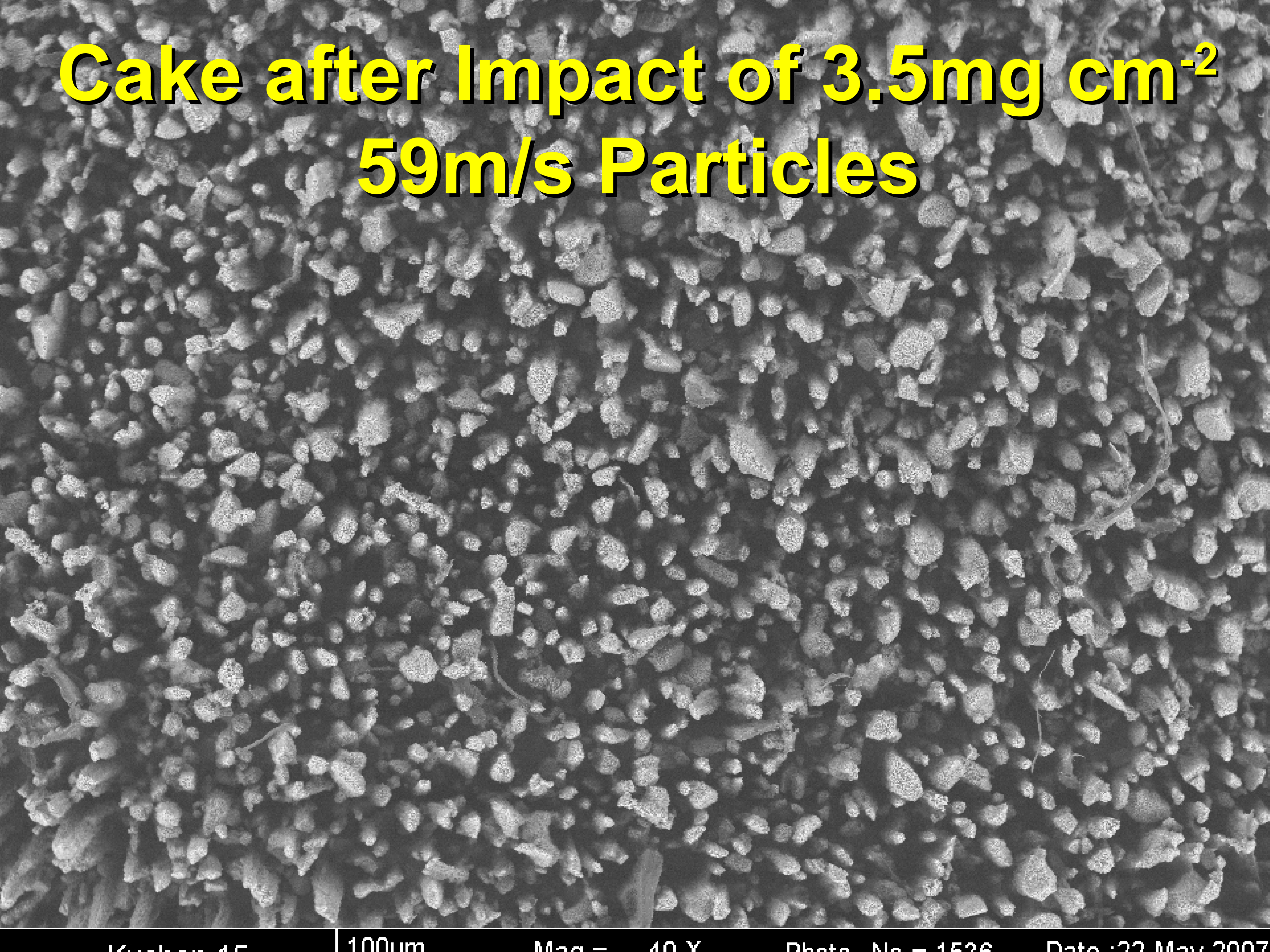
- Impact of micron sized particles leads to a surface compaction of agglomerates

Cake after Impact of 3.5mg cm^{-2} 44m/s Particles

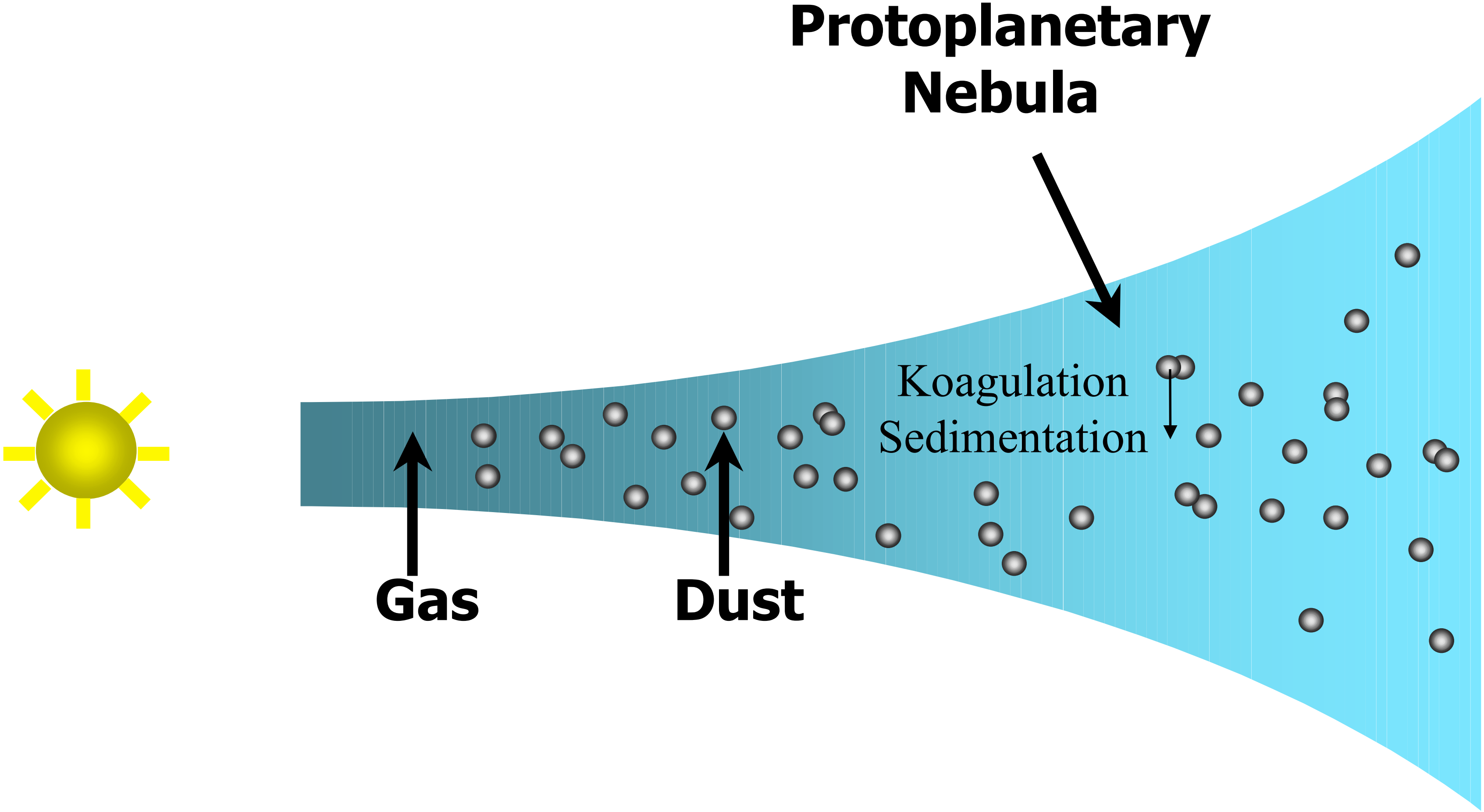


$\text{phi} = 1 - 3.08 / (n + 1.13)$ (Langemaat 2001)

Cake after Impact of 3.5mg cm^{-2} 59m/s Particles



Introduction



Protoplanetary Nebula

Koagulation

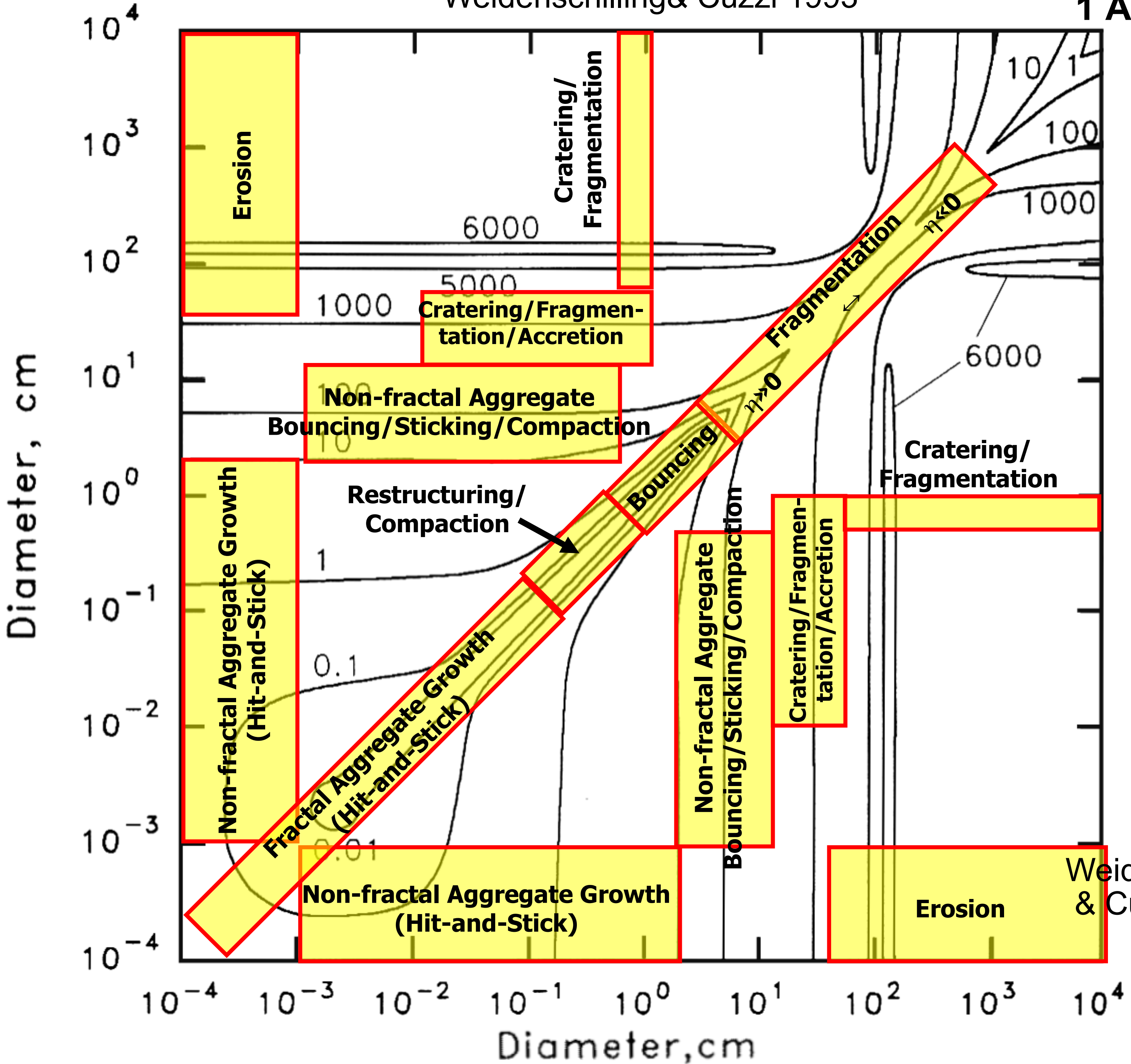
Sedimentation

Gas

Dust

Weidenschilling& Cuzzi 1993

1 AU



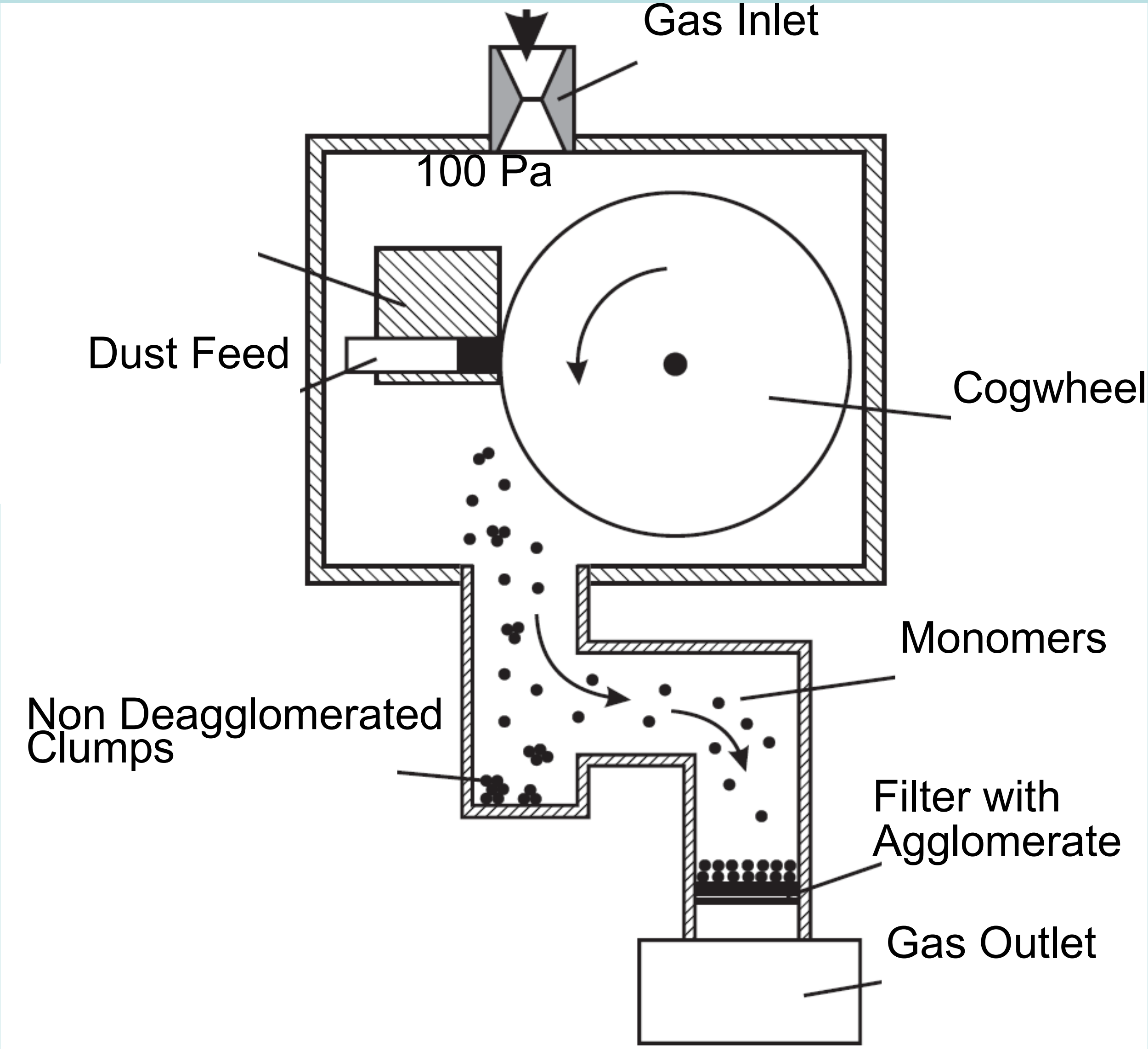
Weidenschilling & Cuzzi 1993

A COMPILATION

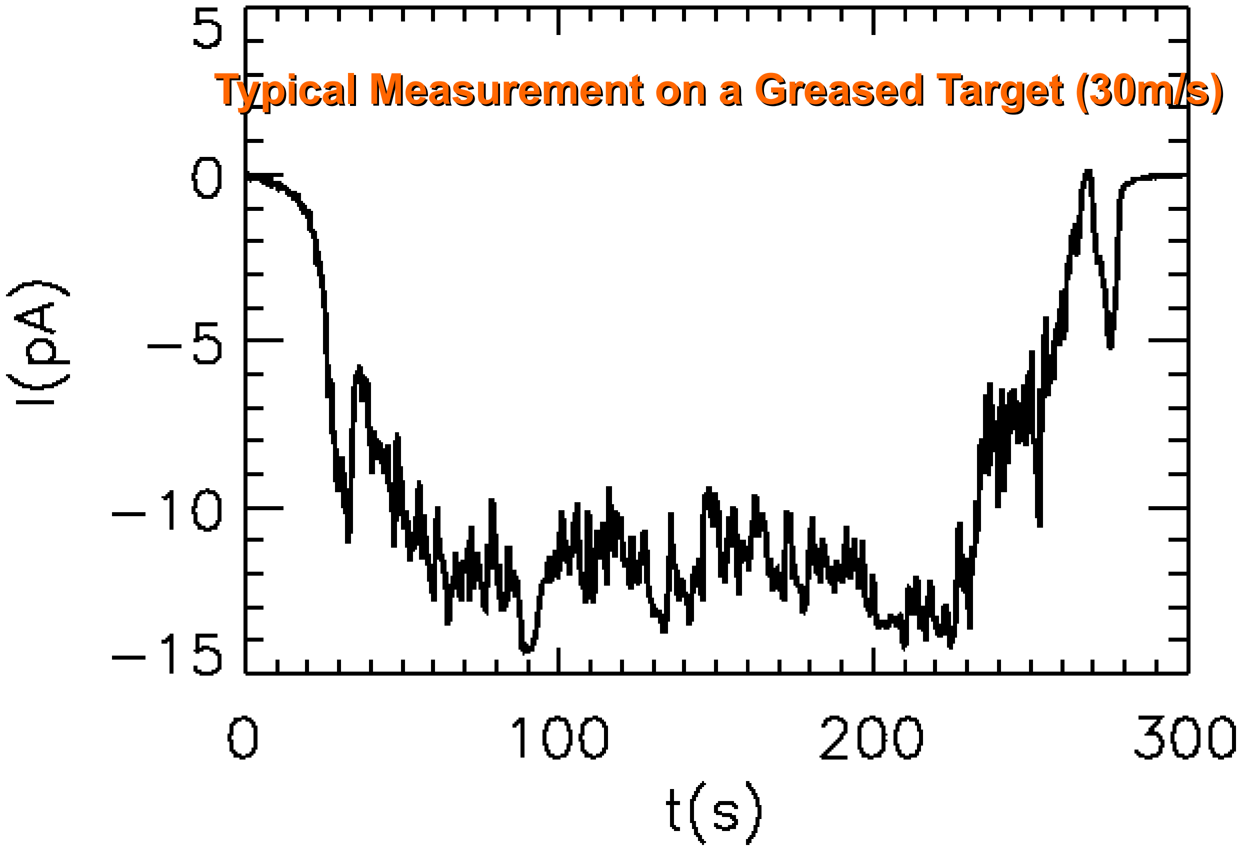
EXPERIMENTS

Target Agglomerate Production

(Blum & Schräpler 2004)

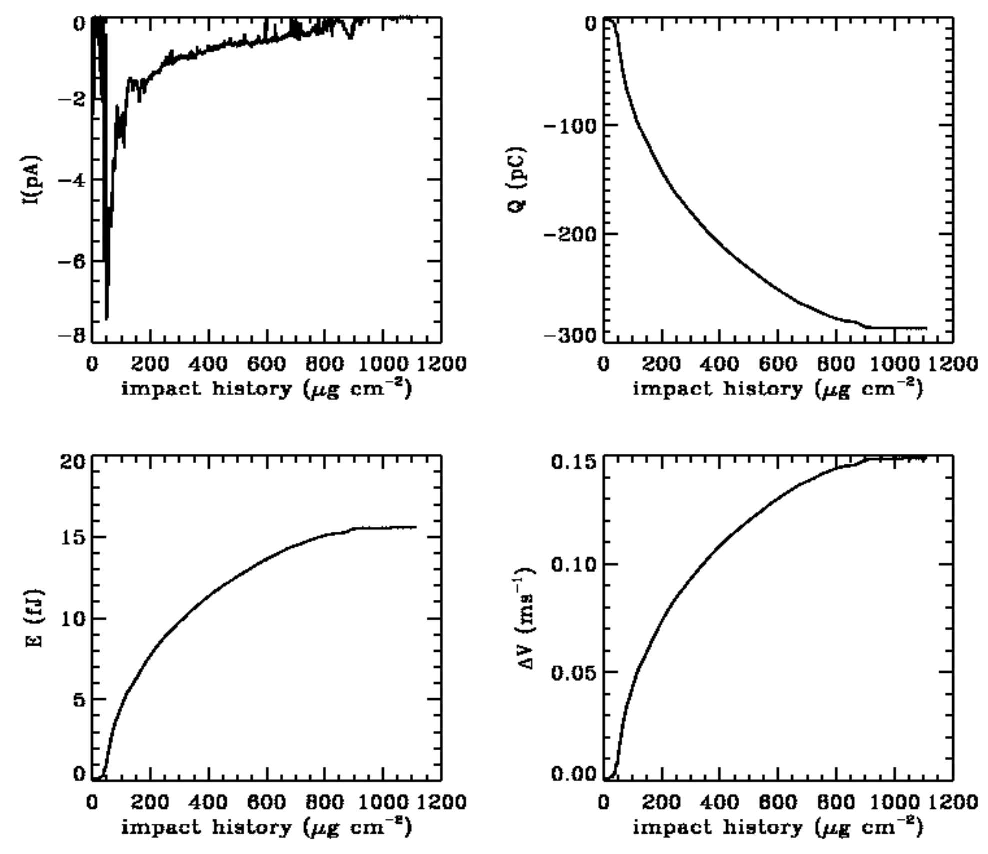


Preliminary Measurement Procedures: Tribo Charging

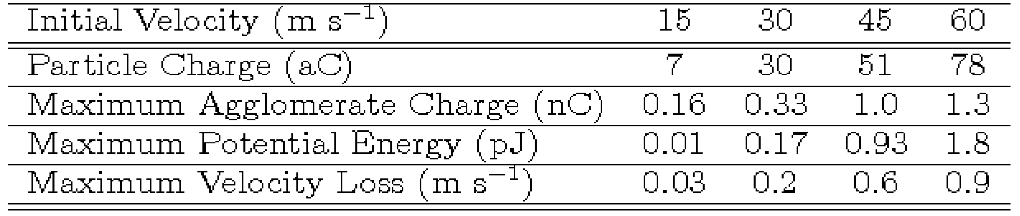


Velocity Loss of an Impactor on a Cake

30m/s measurement:



All measurements:

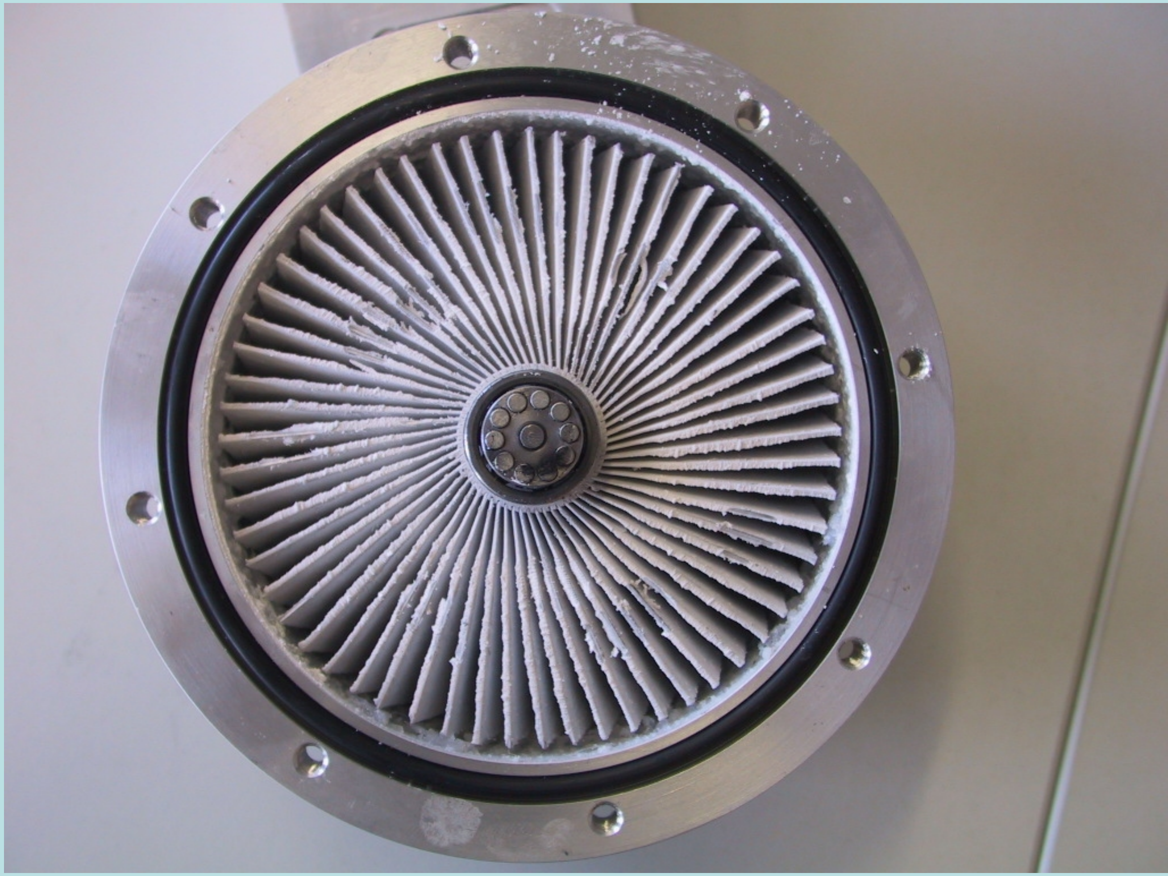


Initial Velocity (m s^{-1})	15	30	45	60
Particle Charge (aC)	7	30	51	78
Maximum Agglomerate Charge (nC)	0.16	0.33	1.0	1.3
Maximum Potential Energy (pJ)	0.01	0.17	0.93	1.8
Maximum Velocity Loss (m s^{-1})	0.03	0.2	0.6	0.9

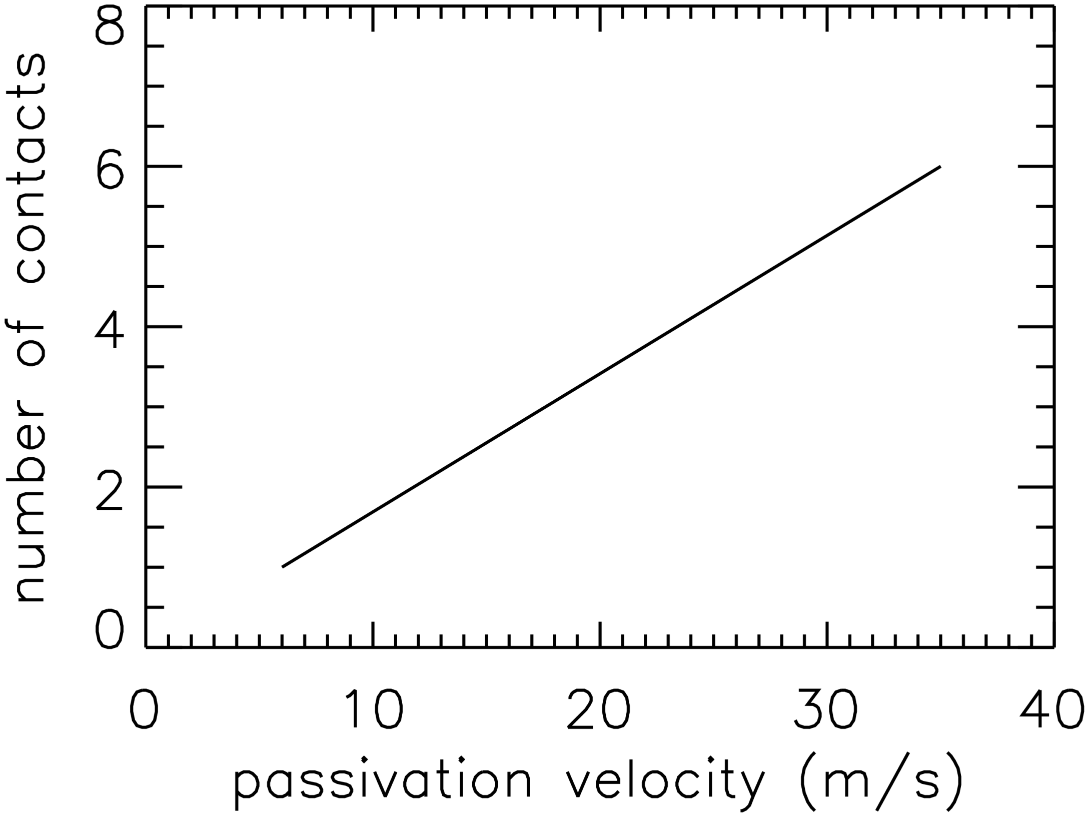
Particle Contact Force is 10^4 Times Larger Than the Electrical Force

Velocity Filter

- Removes Agglomerates
- Velocity FWHM of Monomers: 17%



Predicted number of particle contacts that passivate the agglomerate

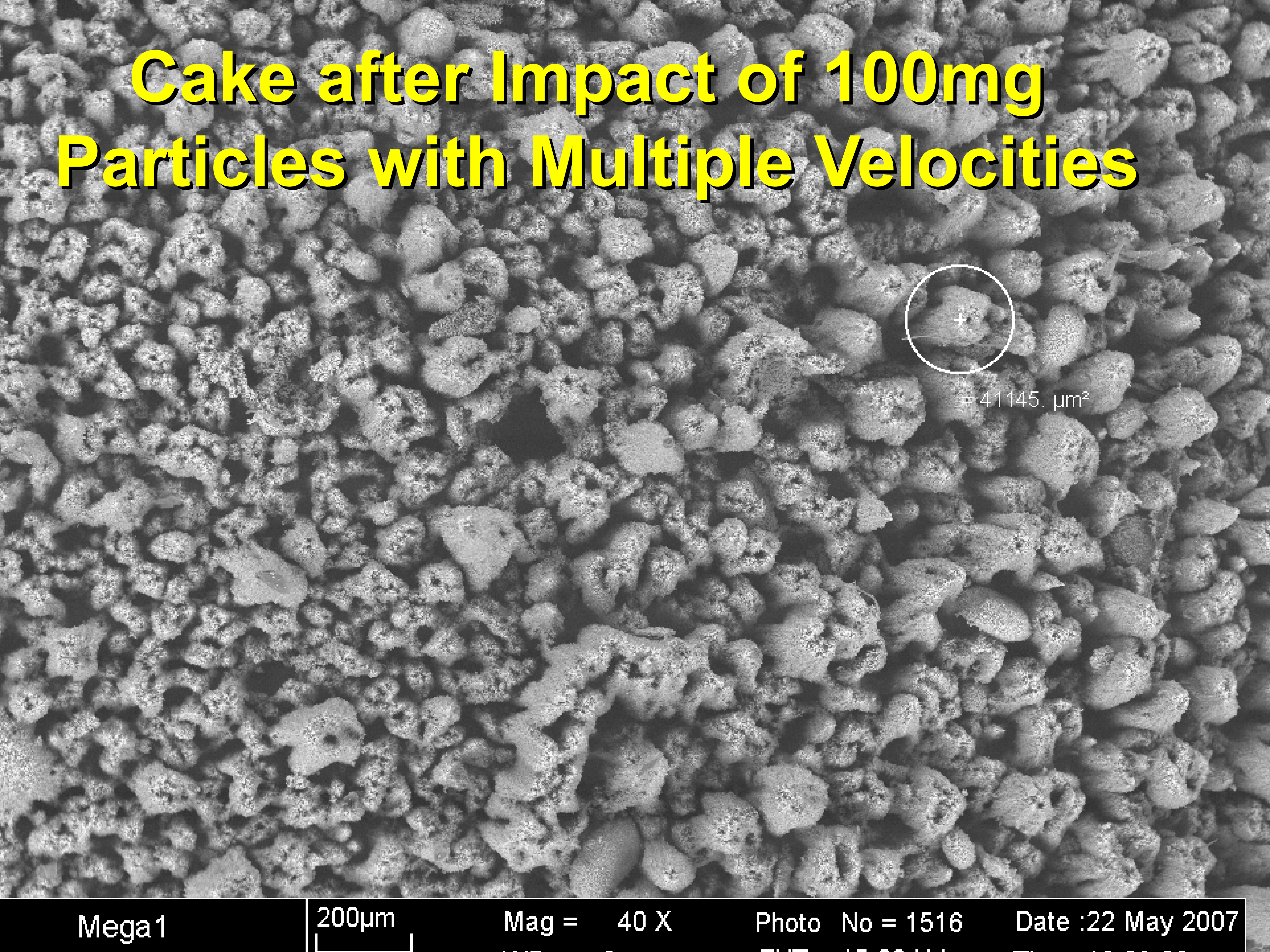


Surface Texturing

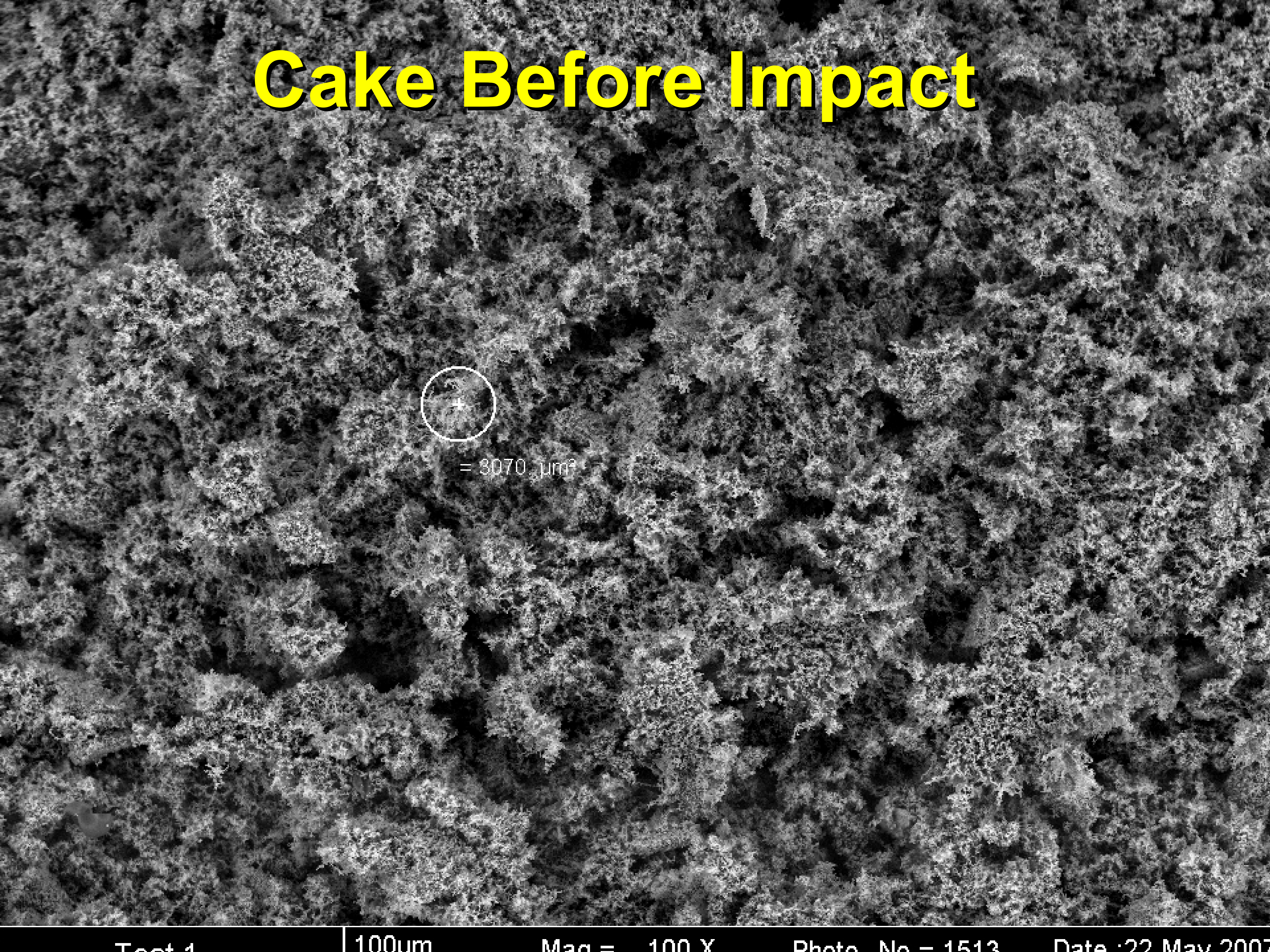
Theoretical Models of Kostoglou & Konstandopoulos (2000) :

- Erosion Strengh varies by a few percent over the particle impact angle
- Erosion Minima are at perpendicular and grazing impacts

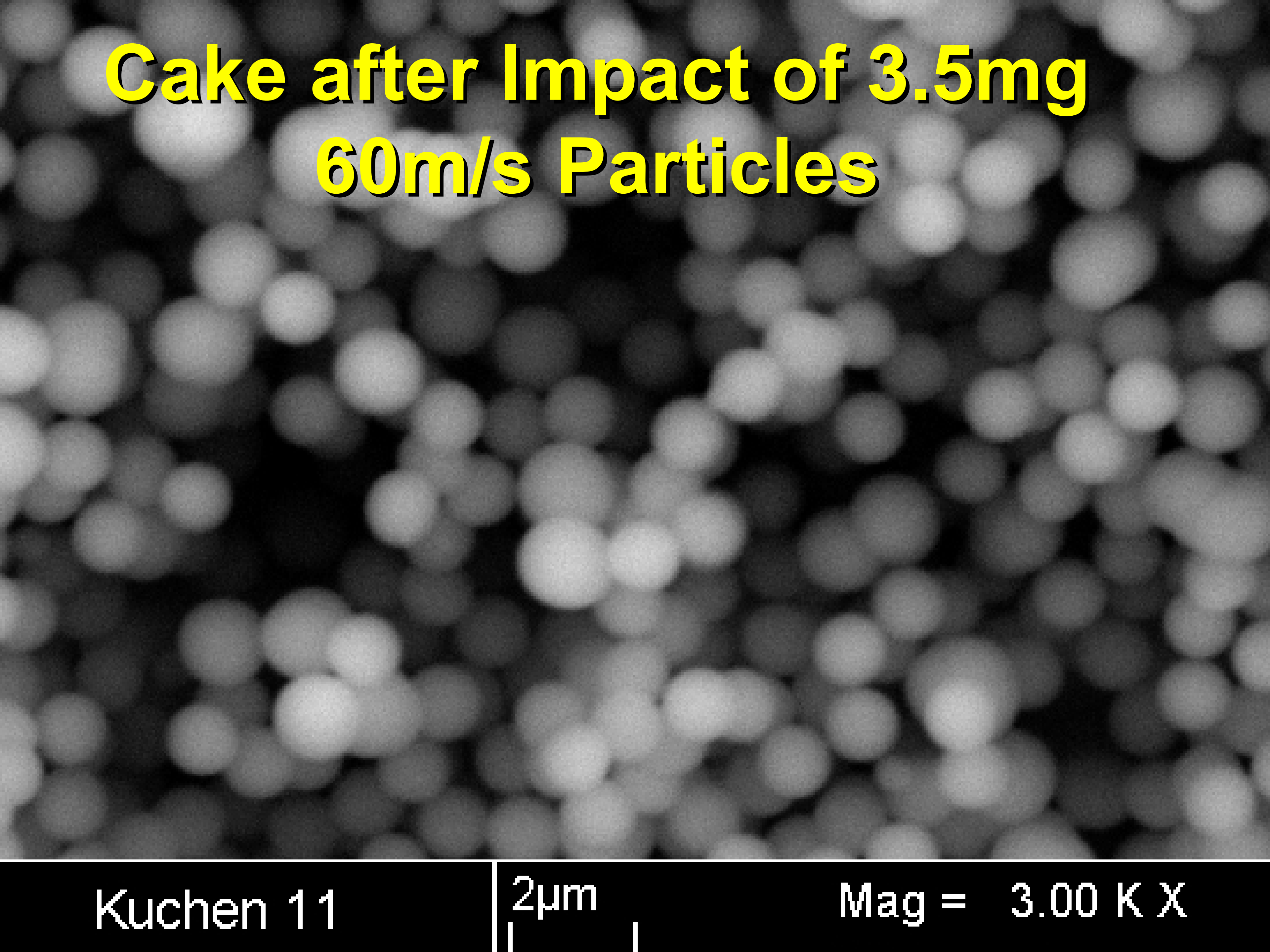
Cake after Impact of 100mg Particles with Multiple Velocities



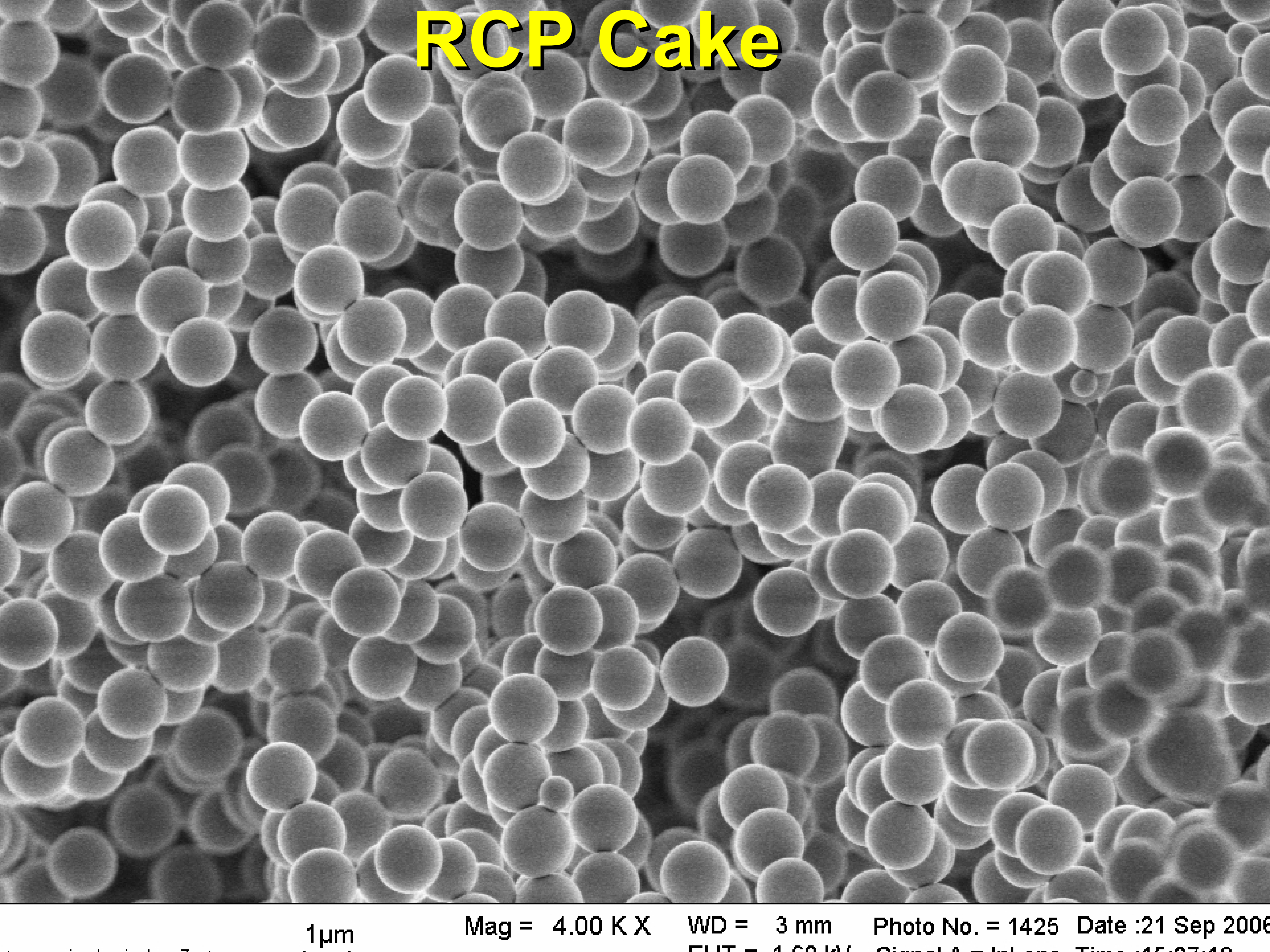
Cake Before Impact



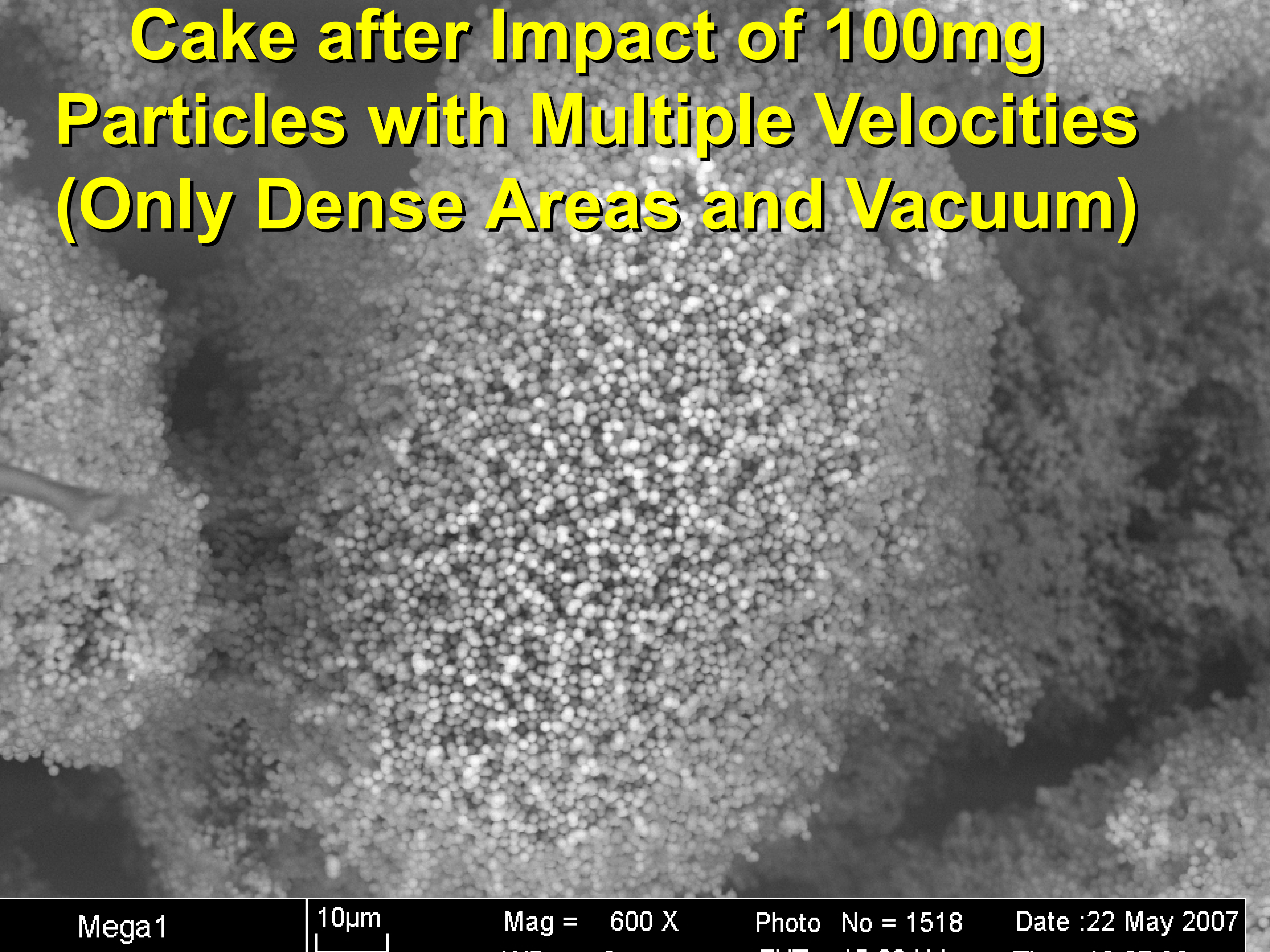
Cake after Impact of 3.5mg 60m/s Particles



RCP Cake

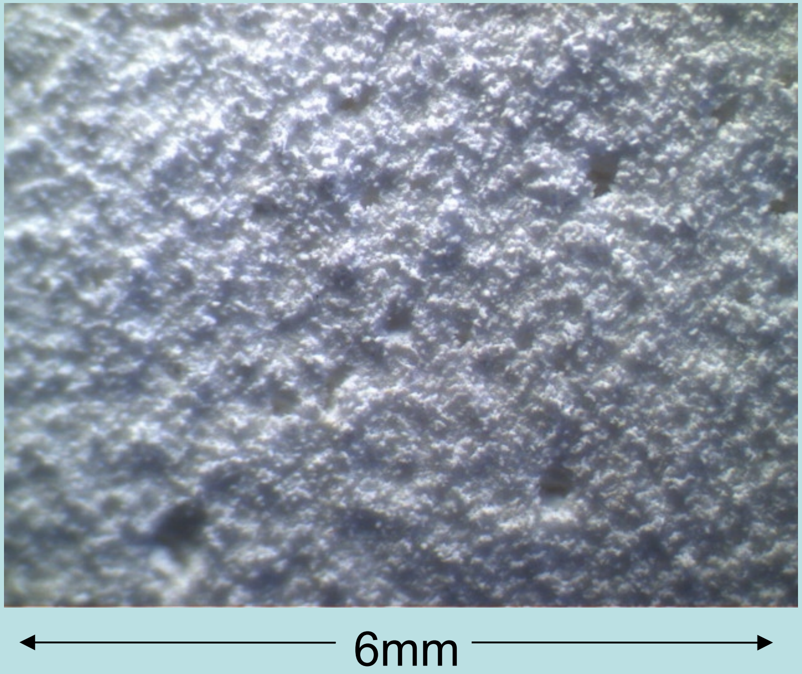


Cake after Impact of 100mg Particles with Multiple Velocities (Only Dense Areas and Vacuum)

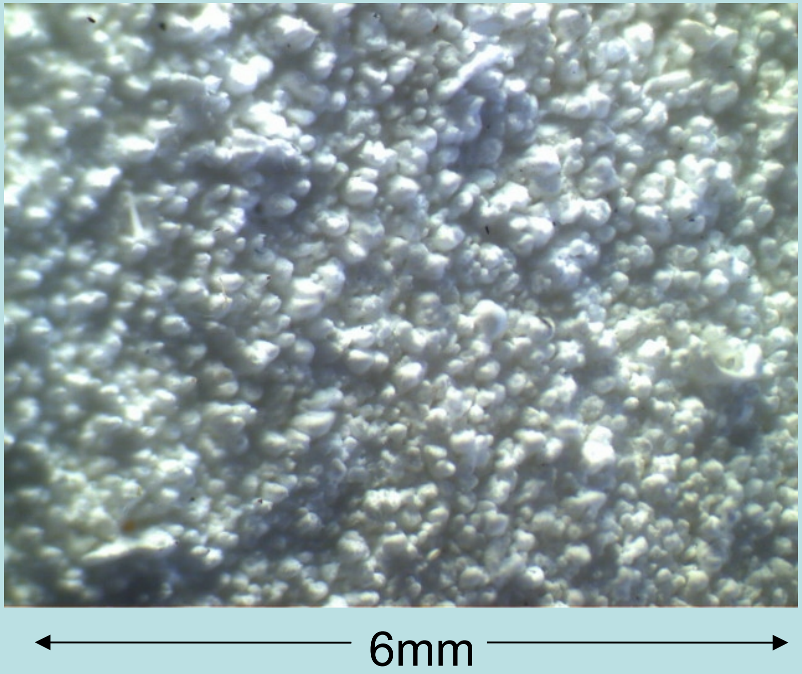


Erosion and Surface Roughness

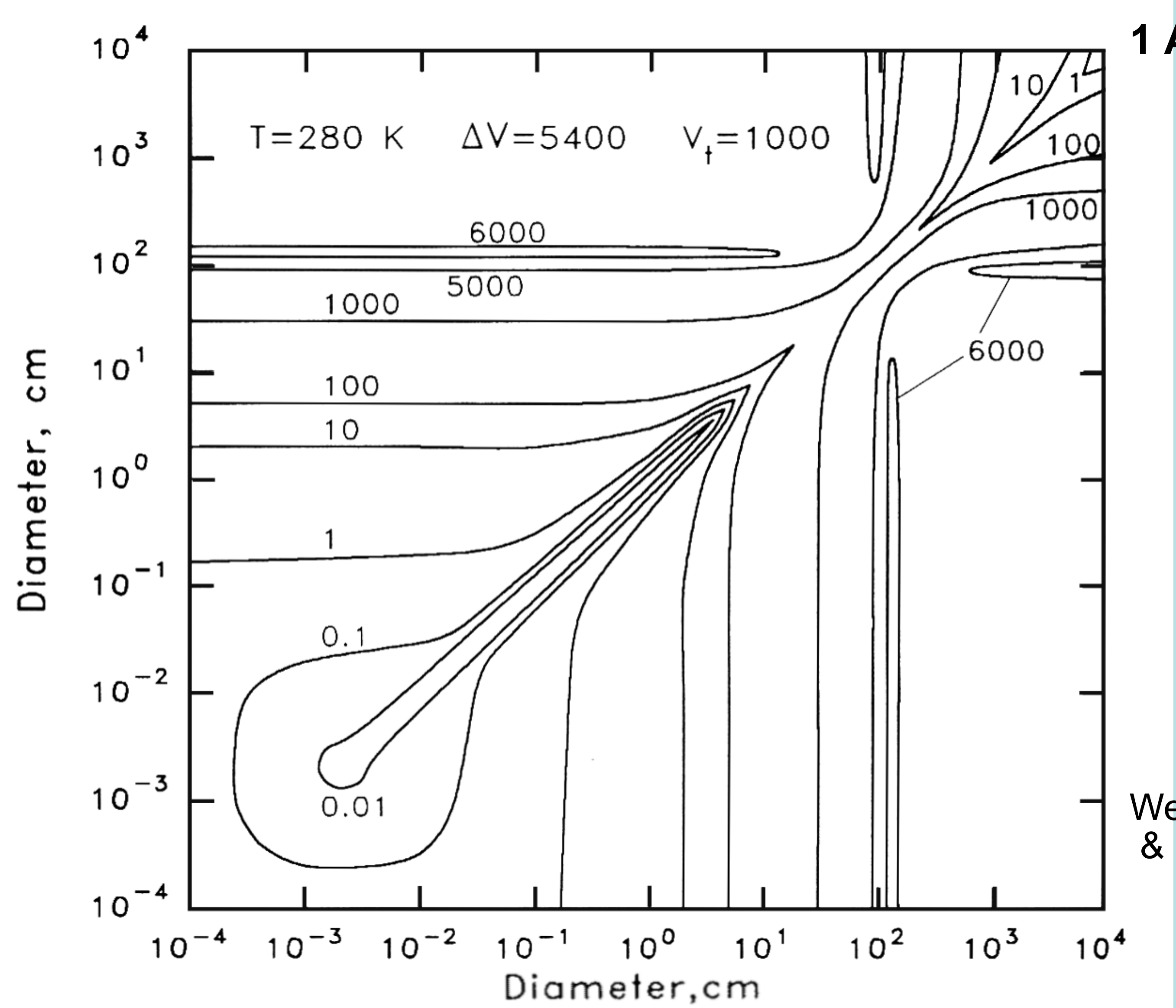
Impact: 30m/s   4mg/cm²



Impact: Multiple Velocities 100mg/cm²



A Model for the Collision Velocities Between Protoplanetary Dust Grains



Weidenschilling & Cuzzi 1993

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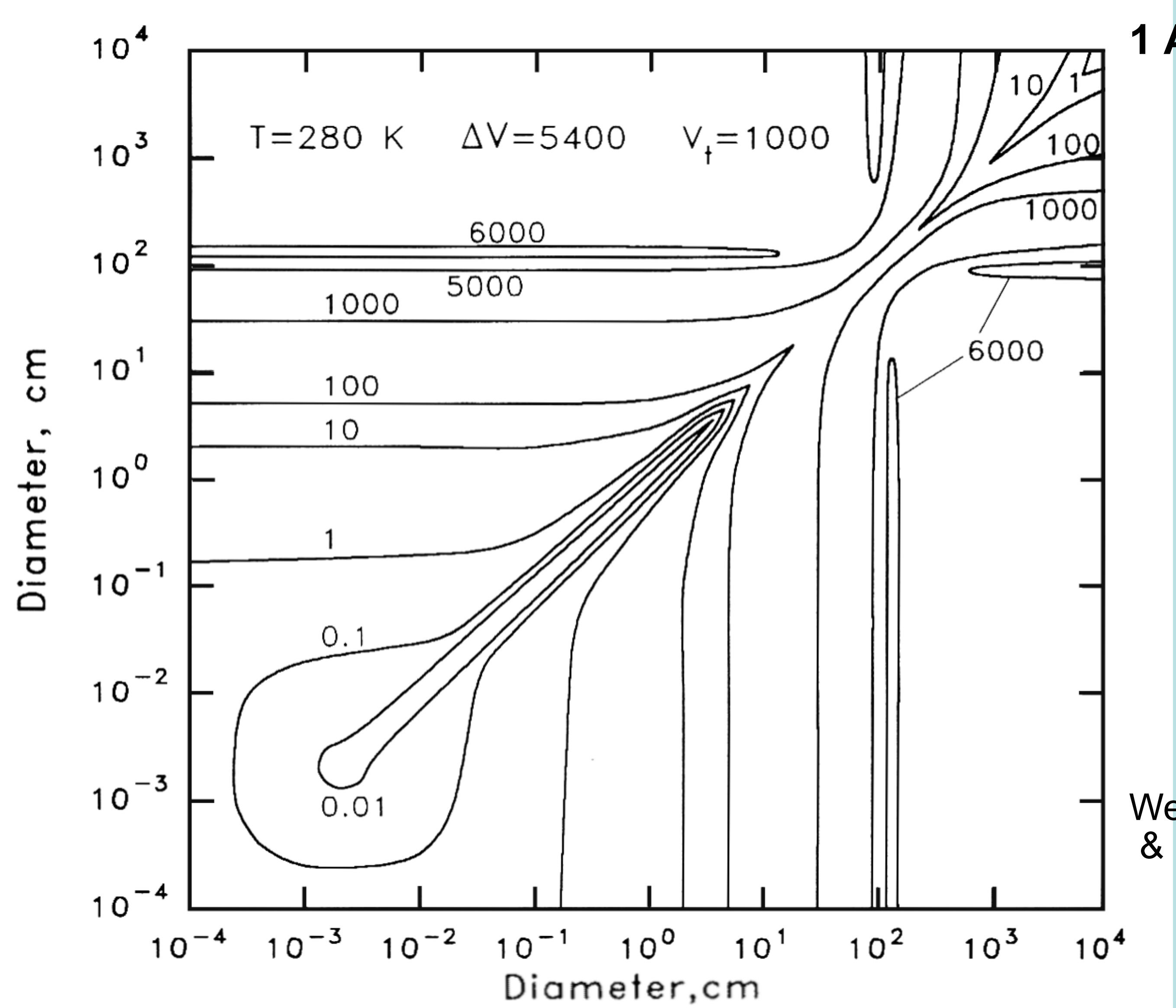

1 AU

Weidenschilling & Cuzzi 1993

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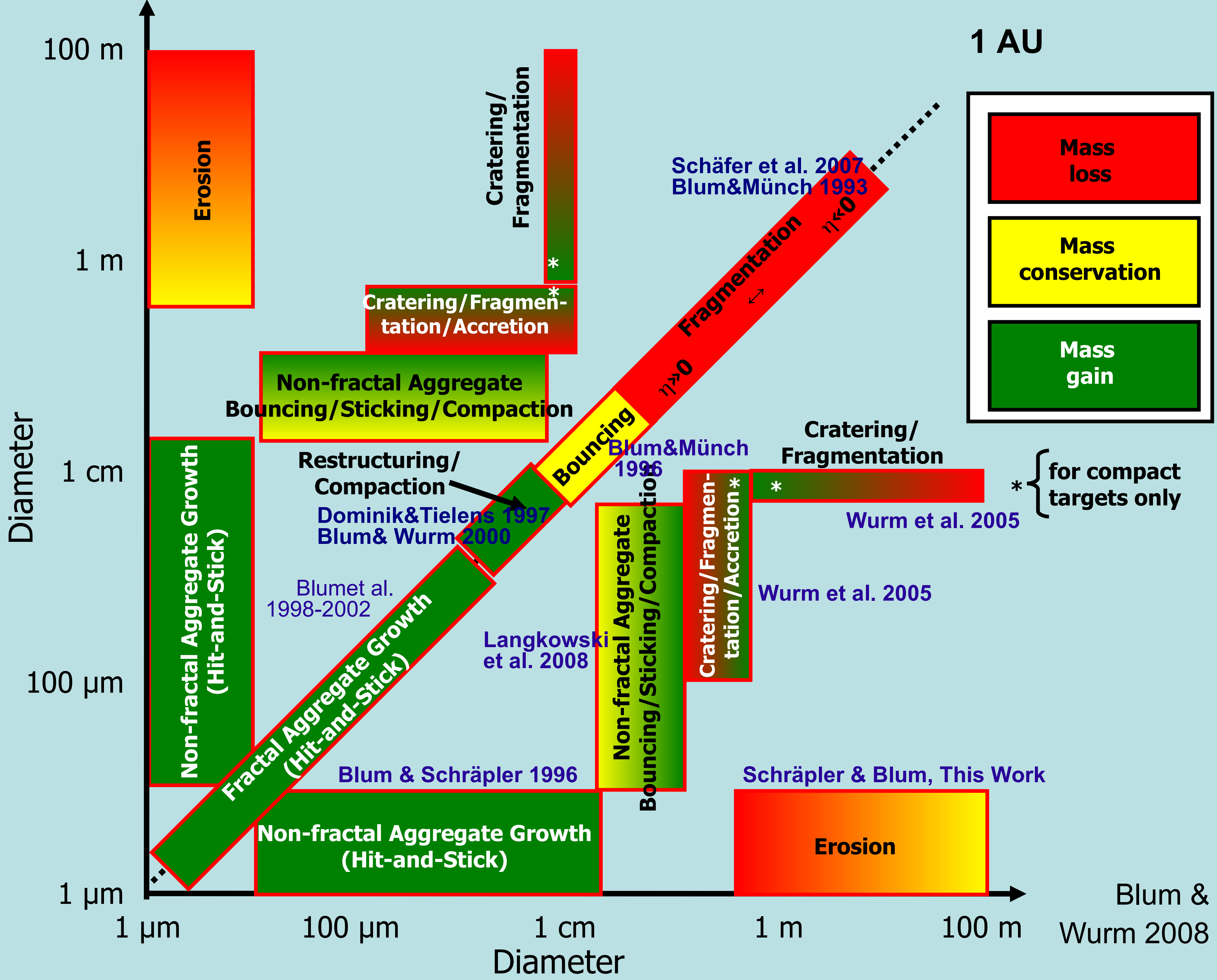
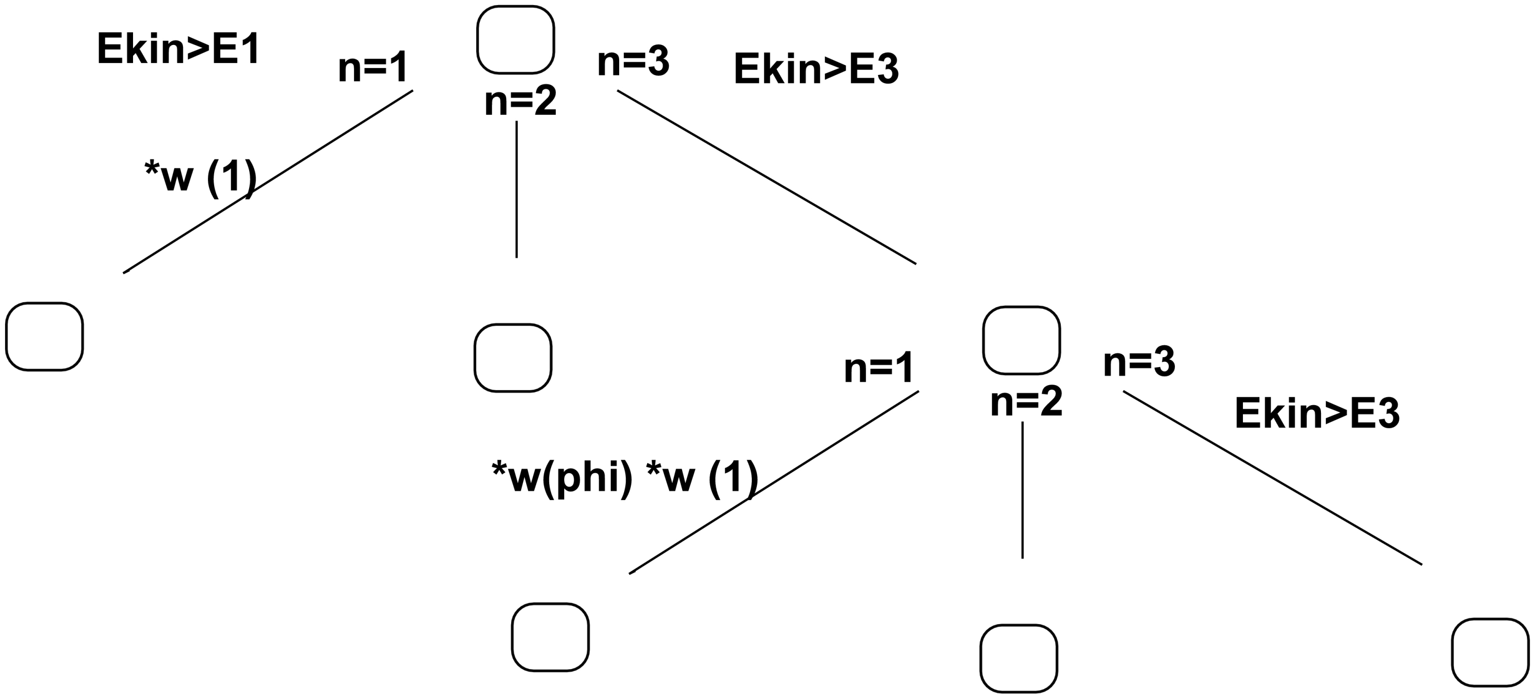


Blum & Wurm 2008



Ekin>E1

n=1

n=2

n=3

Ekin>E3

*w (1)

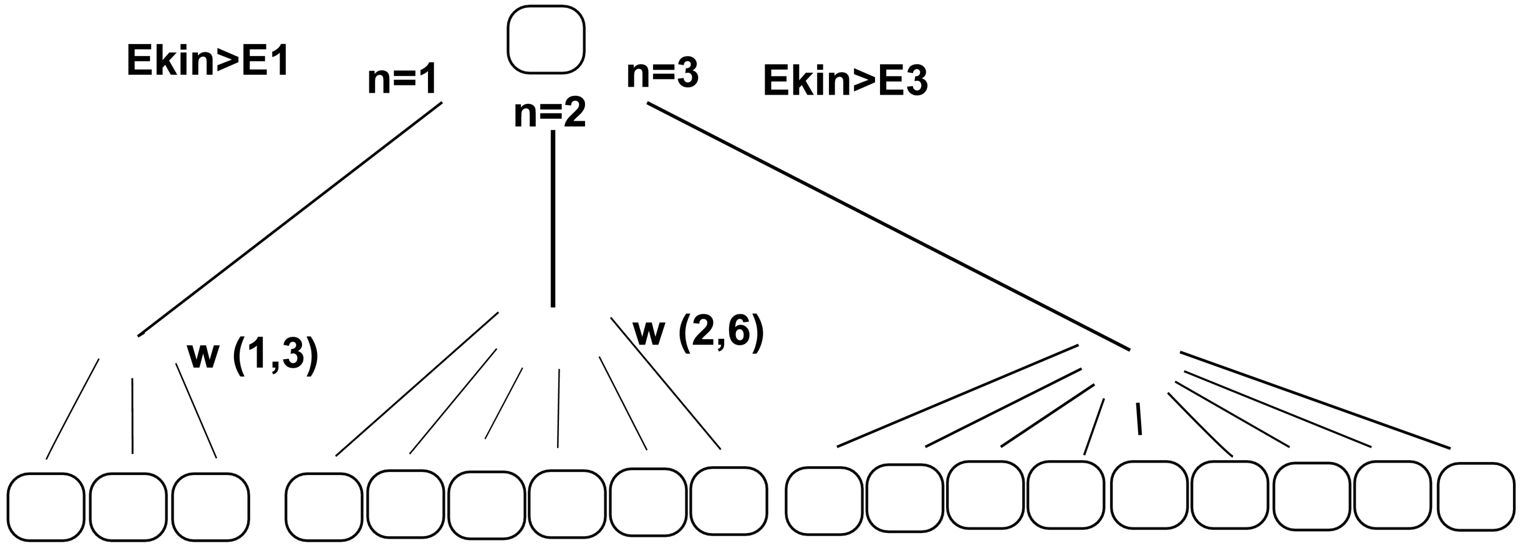
n=1

n=2

n=3

Ekin>E3

*w(phi) *w (1)



Ekin>E1

n=1

n=2

n=3

Ekin>E3

w (1,3)

w (2,6)