Improving the Grain Growth model in the outer part of a circumstellar disk

ISIMA student: Marina Galvagni
PI: Pascale Garaud
Collaborators: Christoph Olczak, Farzana Meru

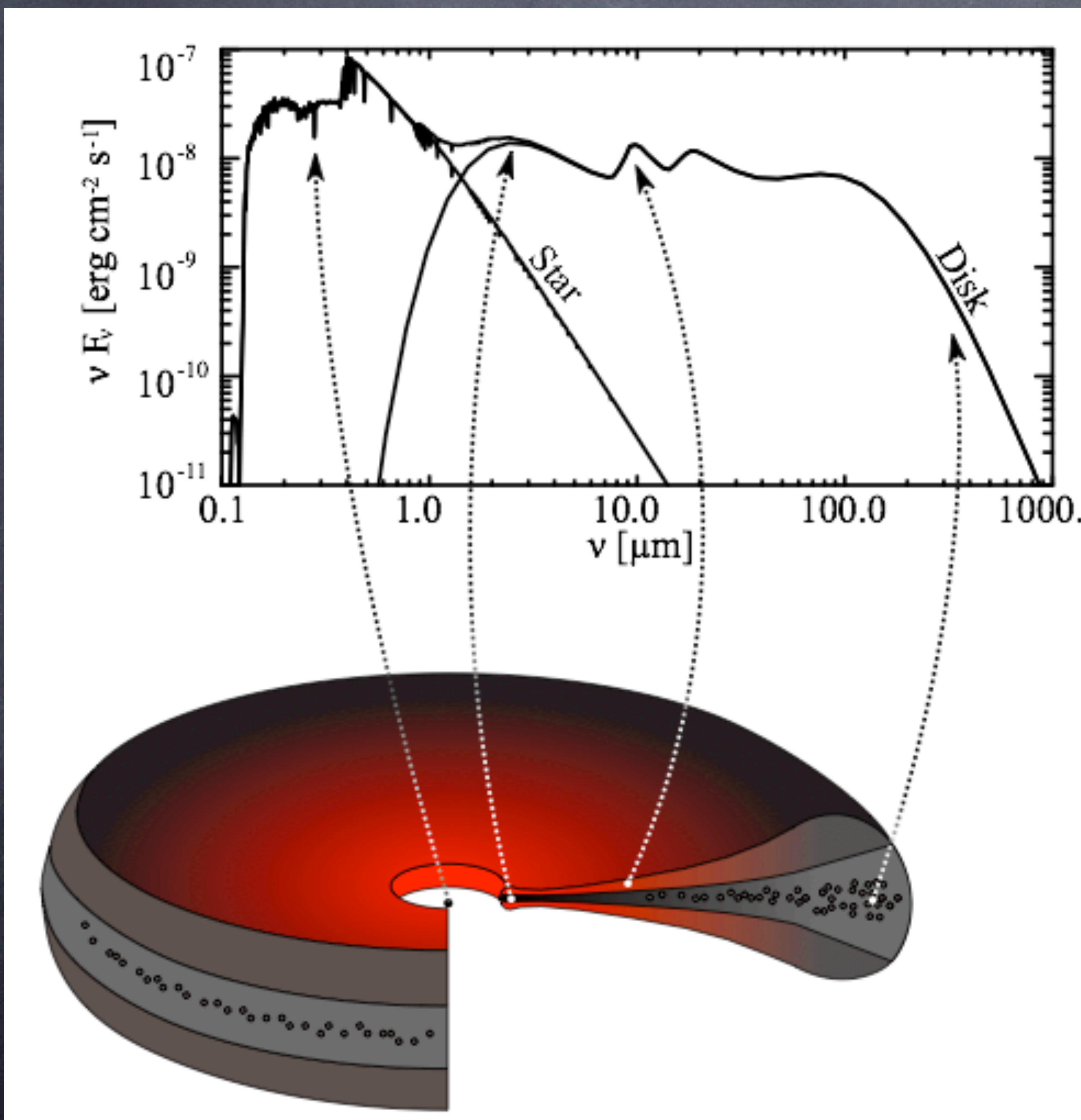
4 August 2011, Beijing

Outline

- Introduction: observational evidences, previous results
- GrOG (GRowth Of Grains)
- Features studied:
  - porosity
  - coagulation and fragmenting probabilities
  - second coagulation region
  - bouncing region
- Results
- Conclusions & future studies

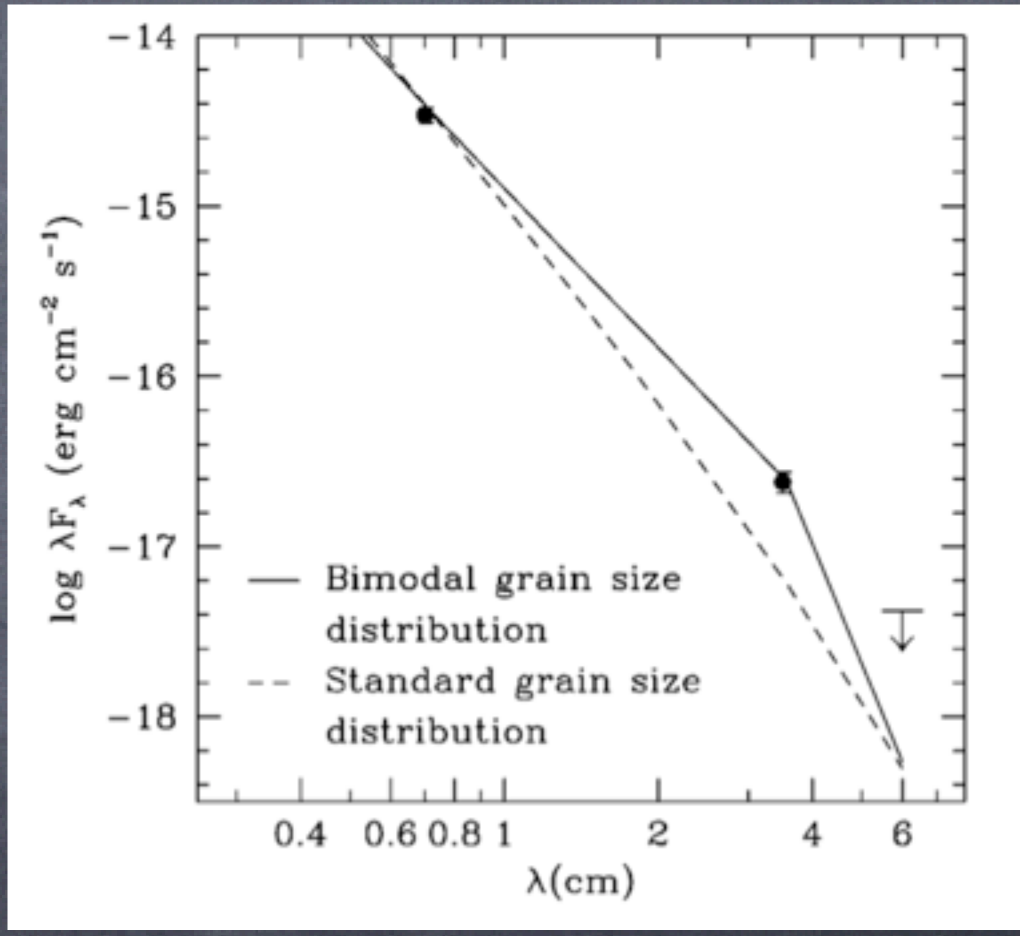
Problem:

Observation: evidence for mm / cm size grains in the outer part of circumstellar disks



Credit: Birnstiel Phd Thesis

Outer part of TW Hya
(r > 10s AU)



(Wilner et al, 2005)

Problem:

Theory:

- mm size grains (or even larger) difficult to grow at 100 AU
- even if successful growth: strong gas coupling causes rapid inward radial drift

→ similar to Meter size problem at 1 AU

Previous results:

- strong dependence on the parameters (in particular, gas-dust ratio)
- Birnstiel (2011): there is a maximum size for the particles at r = 100 AU
- Brauer et al (2008): growth to sizes larger than mm only for fragmenting velocity > 30 m/s

GrOG:
Growth of Grains

Coagulation - Fragmentation solver for Growth of Grains in protoplanetary disks at fixed radius.

Recipe for cooking grains:

- Take a disk with Surface Density ~ 1/r and

  $M_{star} = 0.8\ M_{sun}$

  $M_{disk} = 0.1\ M_{star}$

  $R_{disk} = 200$ AU

  $r = 100$ AU

  $H(r) = 10$ AU

  Dust/Gas = 0.01
- Take as initial distribution of grains a gaussian centered at s = 10 micron

How to bake:

$$\frac{dm}{dt} = \int_{s_{\min}}^{s} \frac{dn}{ds}(s')m(s')\Delta v(s \quad ,s')A(s \quad ,s')\epsilon\, ds'$$

How to bake:

$$\frac{dm}{dt} = \int_{s_{\min}}^{s} \frac{dn}{ds}(s')\, m(s')\, \Delta v(s \quad, s')\, A(s \quad, s')\, \varepsilon \, ds'$$

Particle mass

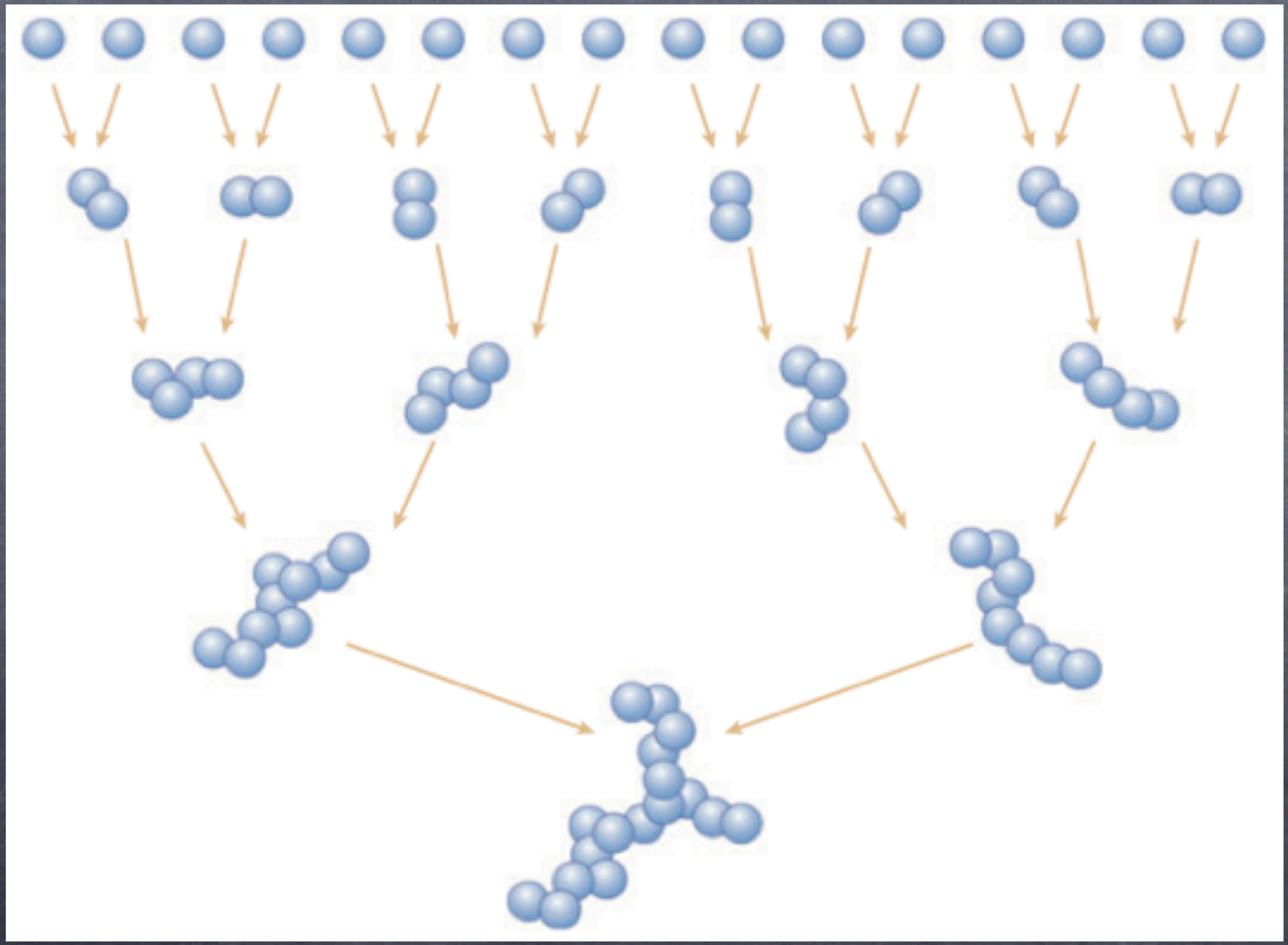
Relative velocity

Cross section

Coagulation & fragmenting efficiency

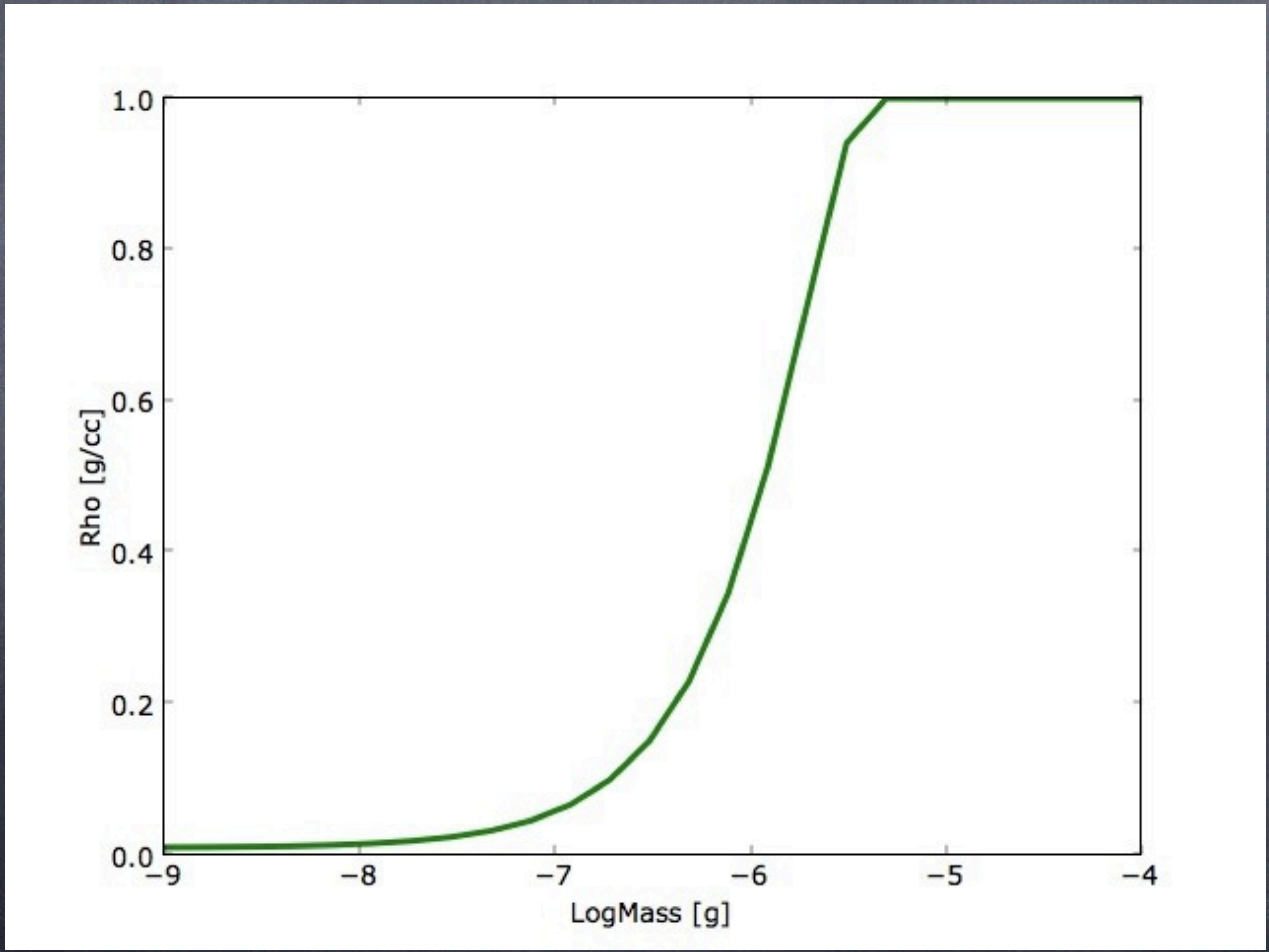
Evolution of the porosity with size

Initial growth is fractal, leading to fluffy particles. Successive collisions compact the particles. (Blurm and Wurm, 2008)



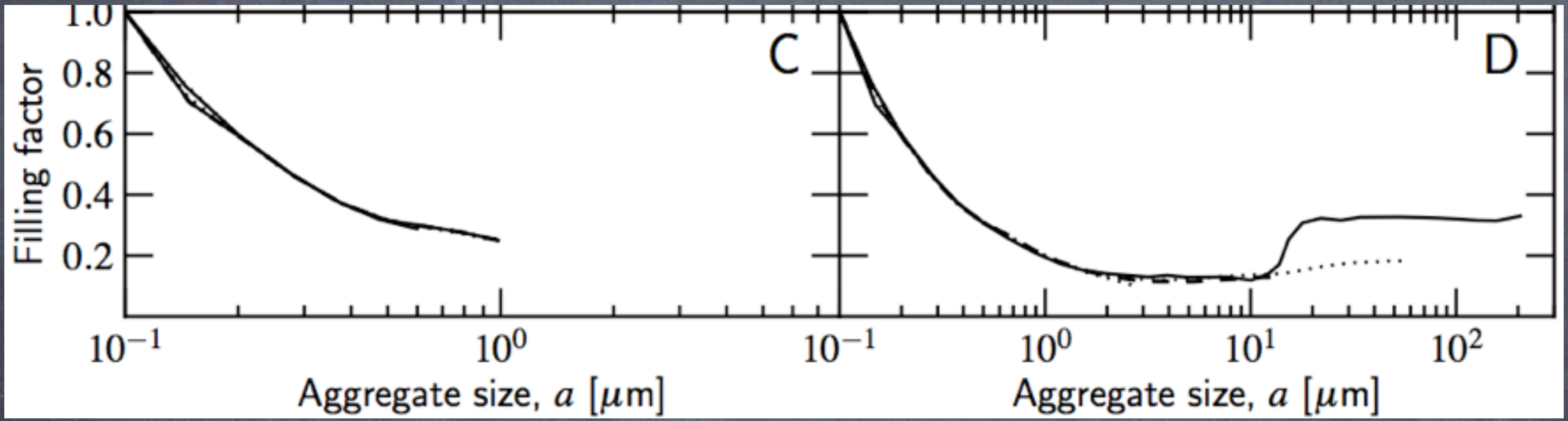
Evolution of the porosity with size

Initial growth is fractal, leading to fluffy particles. Successive collisions compact the particles. (Blurm and Wurm, 2008)



Evolution of the porosity with size

Initial growth is fractal, leading to fluffy particles. Successive collisions compact the particles. (Blurm and Wurm, 2008)

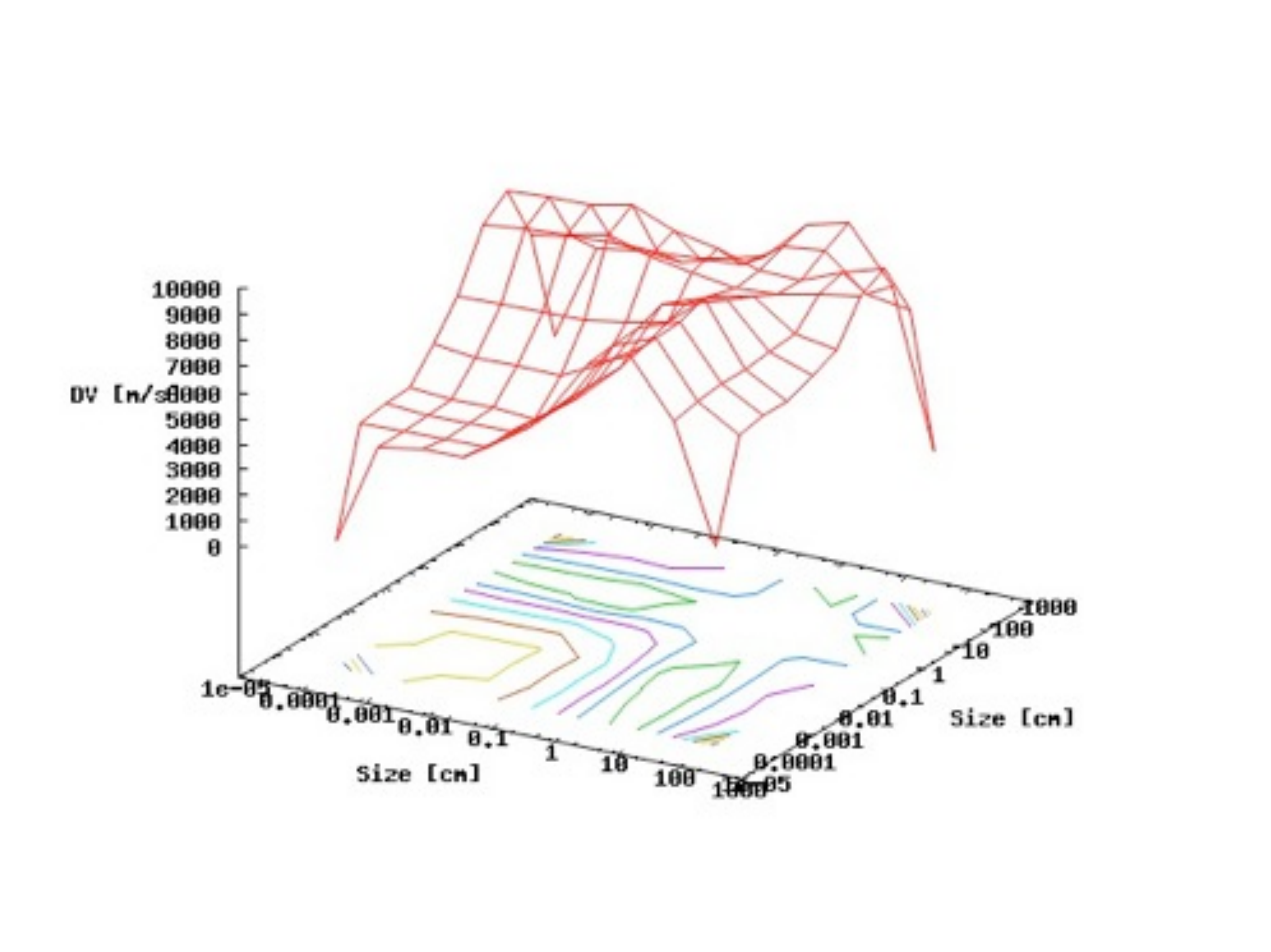


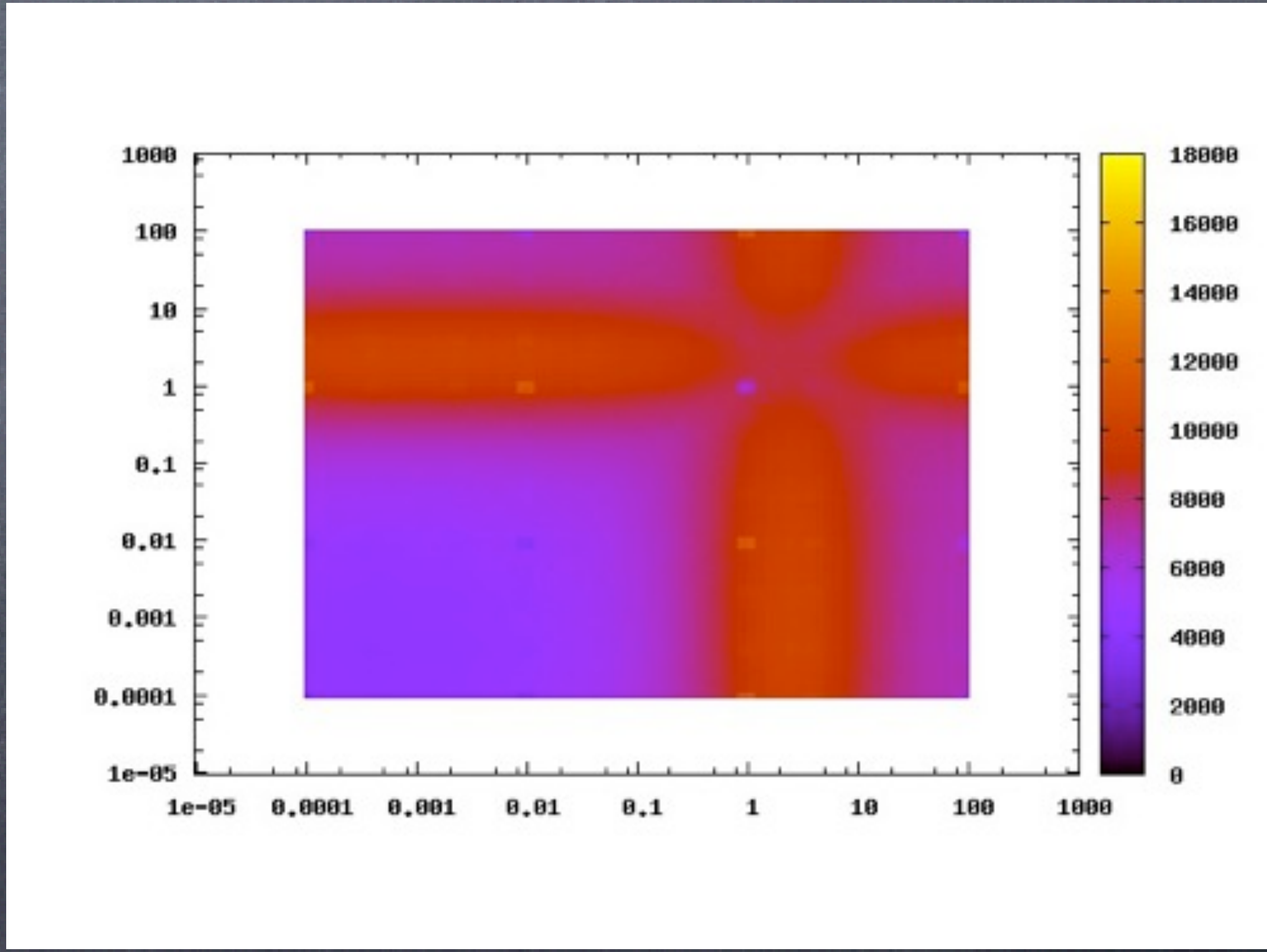
Ormel et al (2011)

Relative velocity

Taken into account:

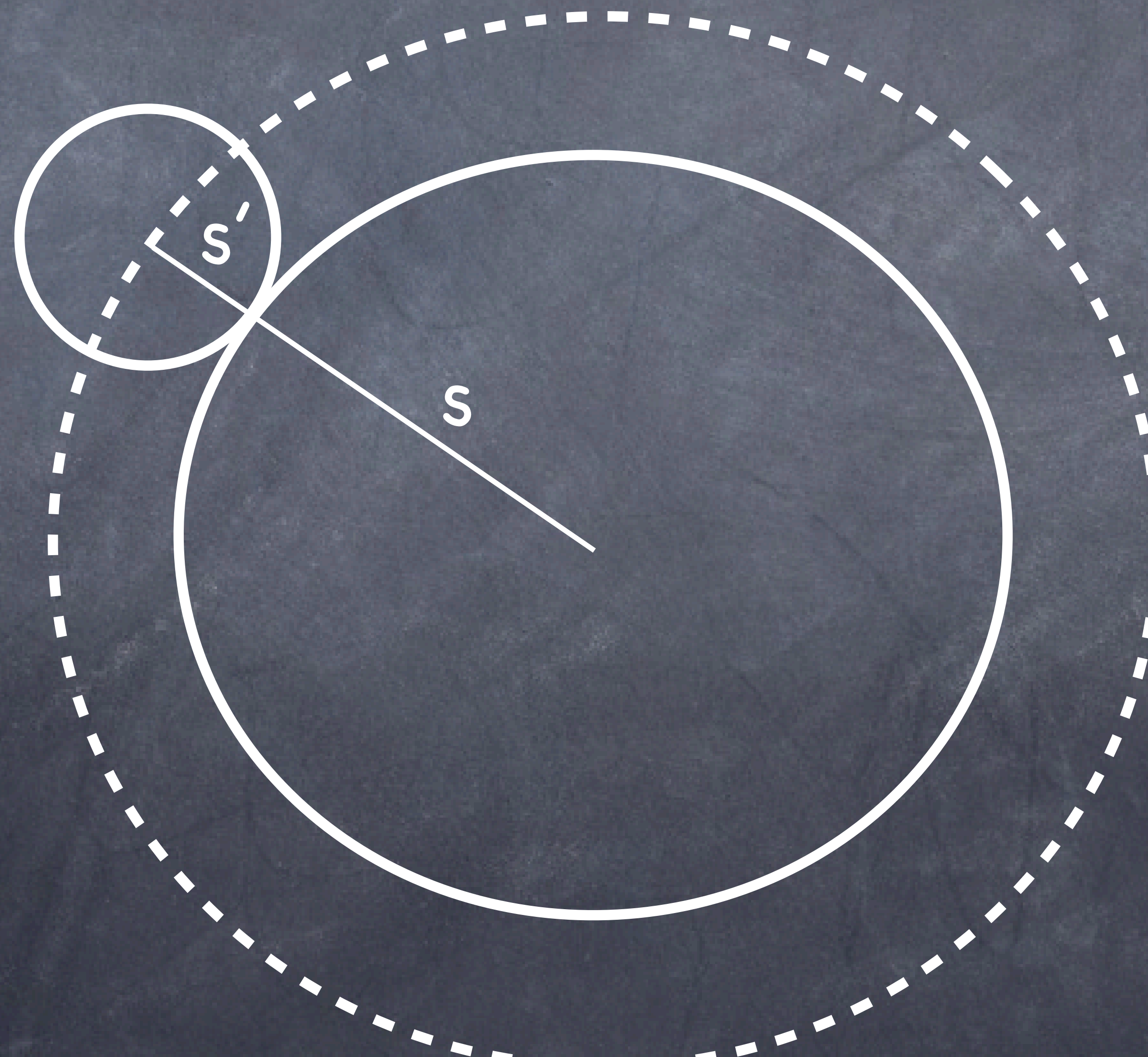
- Brownian motion
- Settling velocity
- Radial drift velocity
- Turbulent velocity





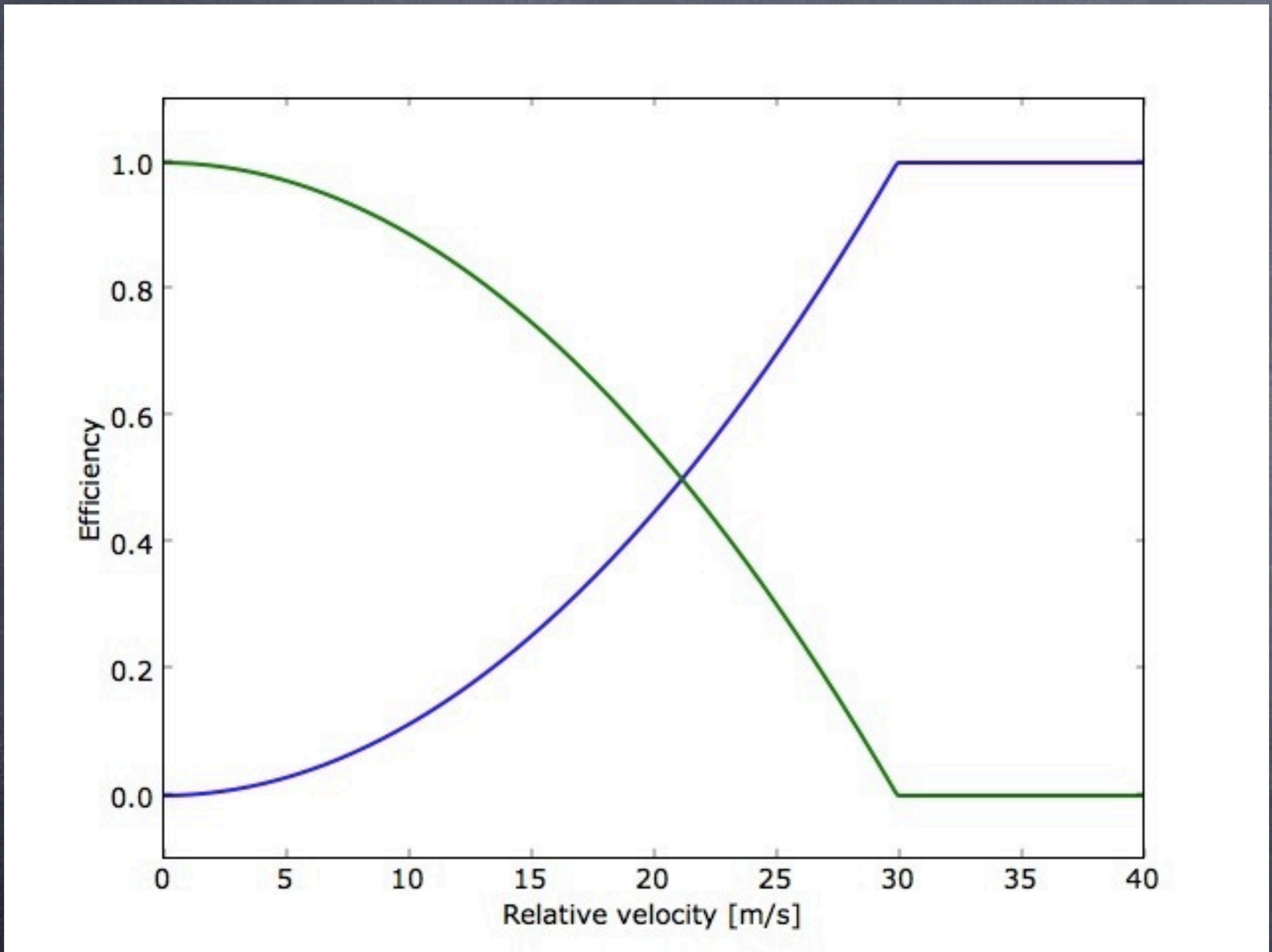
Cross section:

$$A(s,s') = \pi(s+s')^2$$



Reference model: Brauer et al, 2007

- Coagulation + fragmentation



Fragm. prob

$$p_{\mathrm{f}}(\Delta v) = \left(\frac{\Delta v}{v_{\mathrm{f}}}\right)^{\psi} \Theta\left(v_{\mathrm{f}} - v\right) + \Theta\left(v - v_{\mathrm{f}}\right)$$

V_f = 30 m/s

phi = 2.0

Coag. prob =

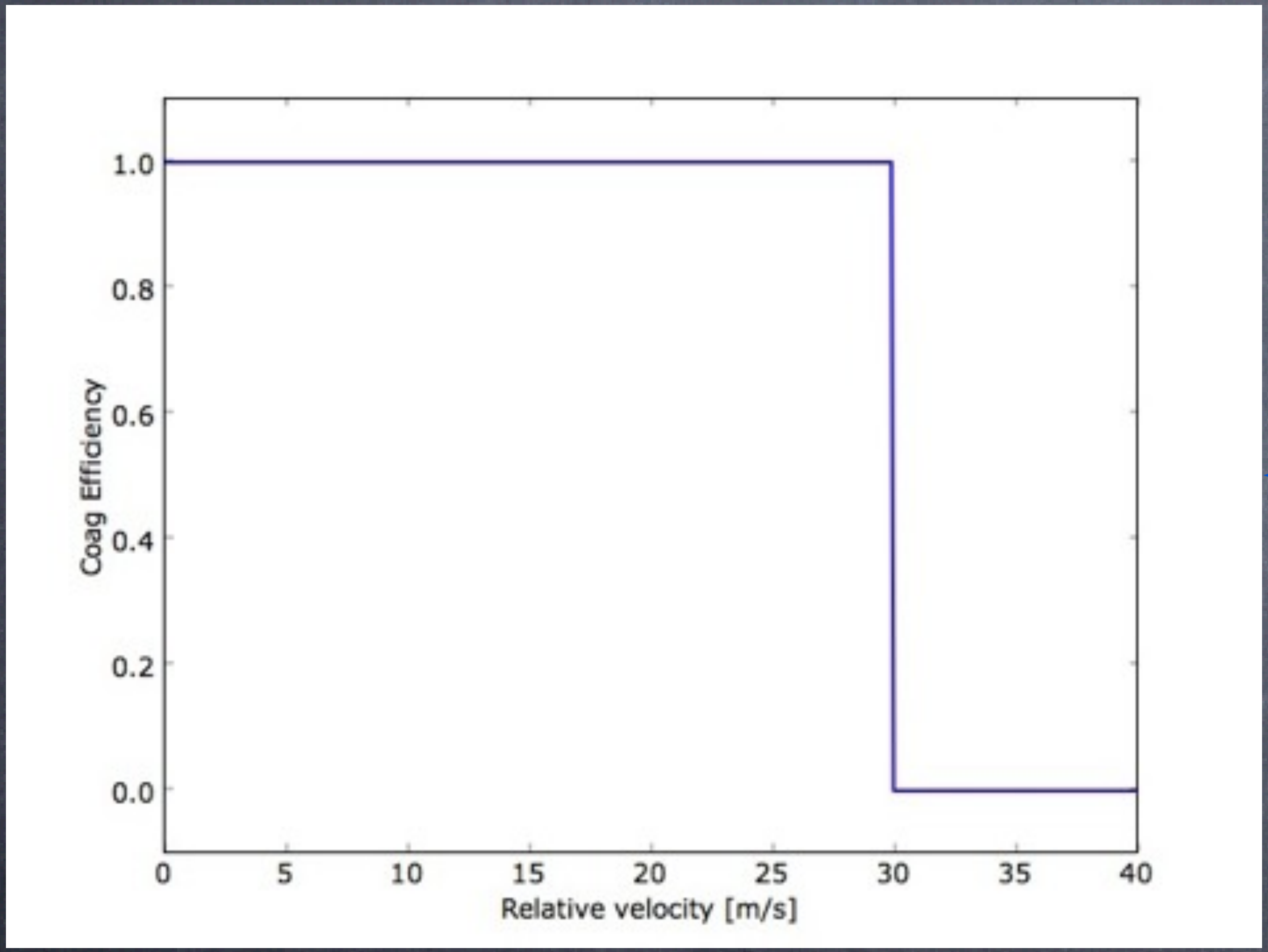
= 1 - fragm. prob

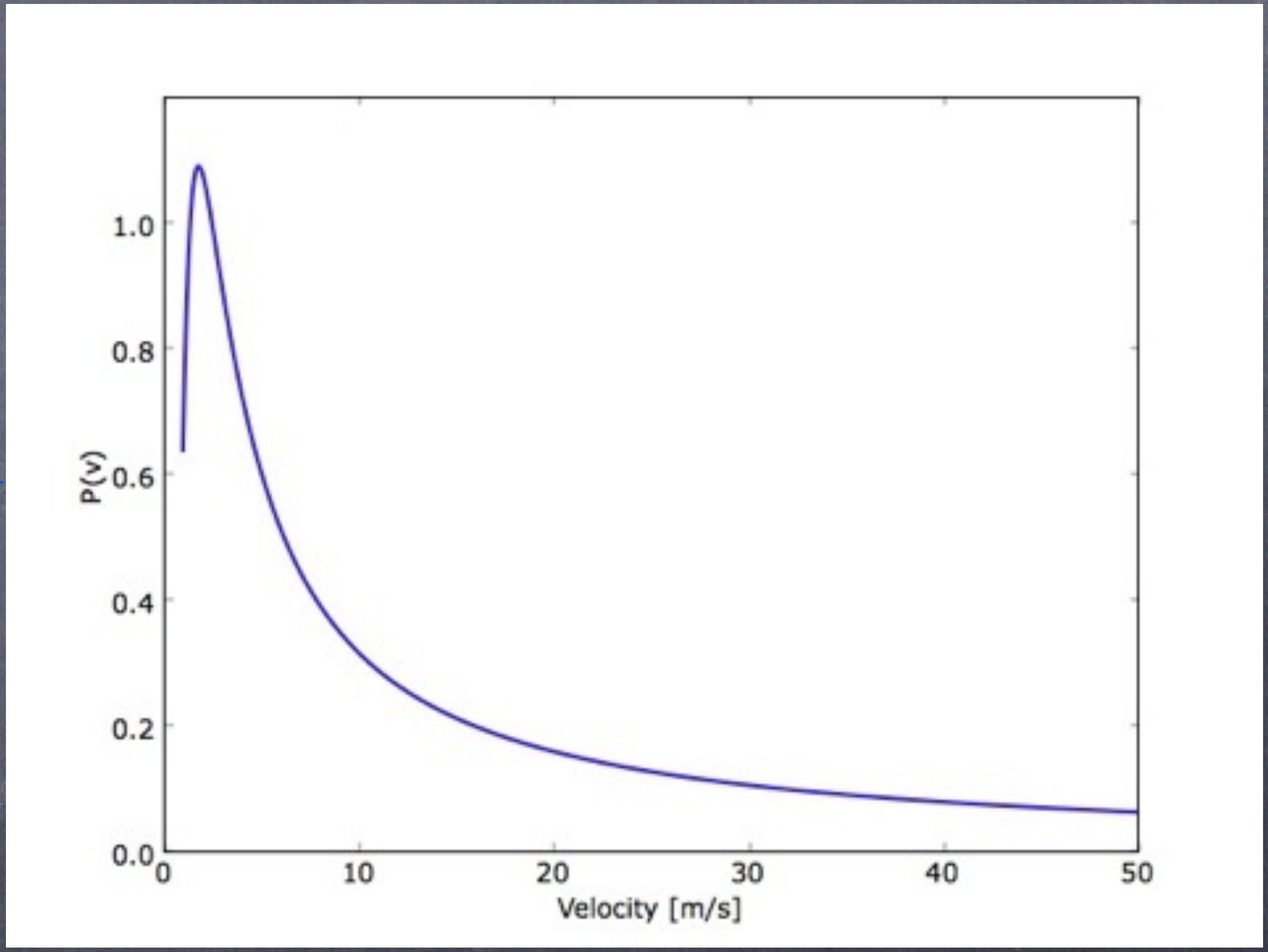
Redistribution of mass after fragmentation: $n(m)\,\mathrm{d}m \propto m^{-\xi}\mathrm{d}m$

with $\xi = 1.83$

Tail model

Step function for the probabilities + maxwellian probability distribution for the velocities

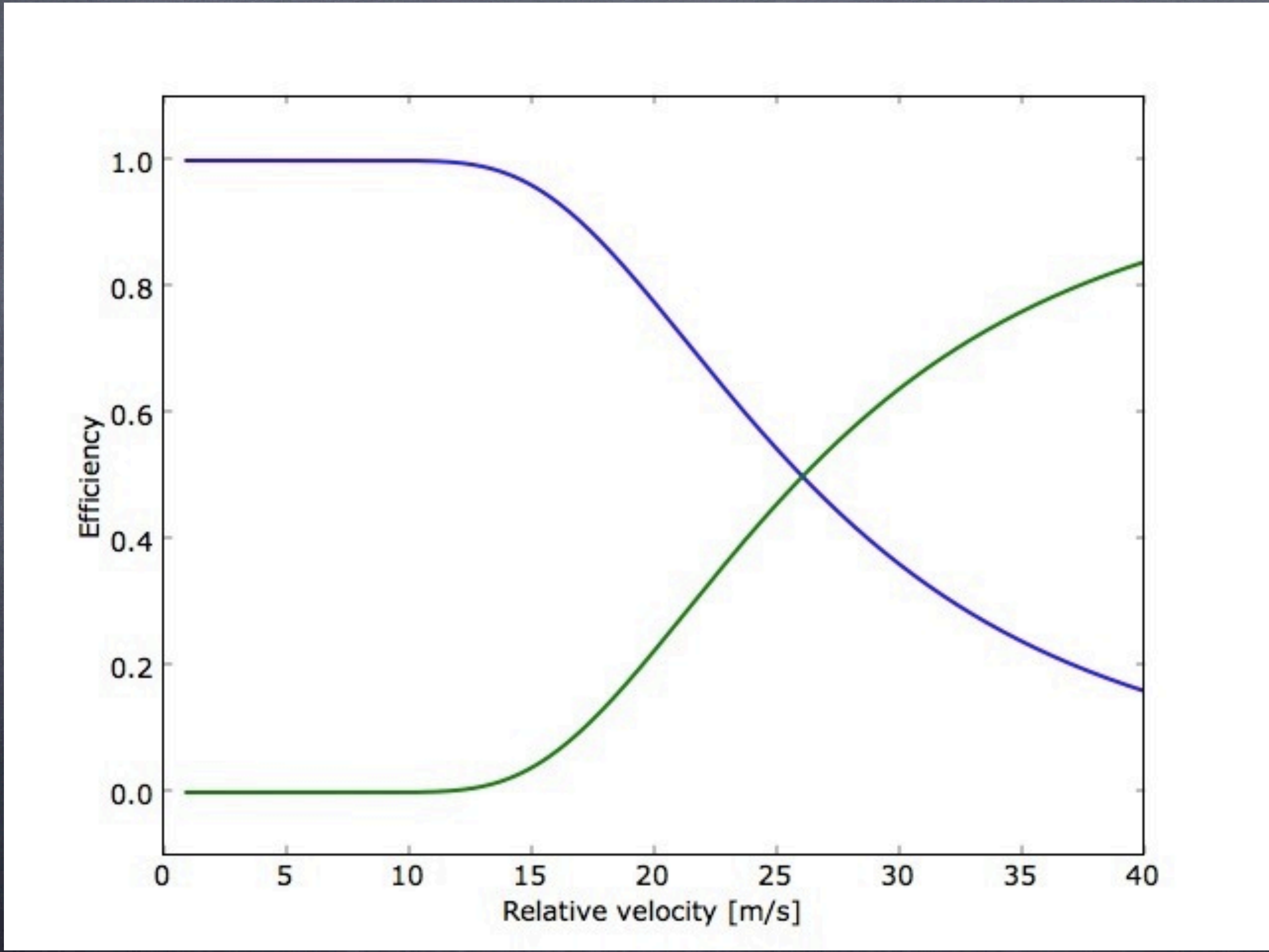




$V_{crit} = 30$ m/s

Tail model

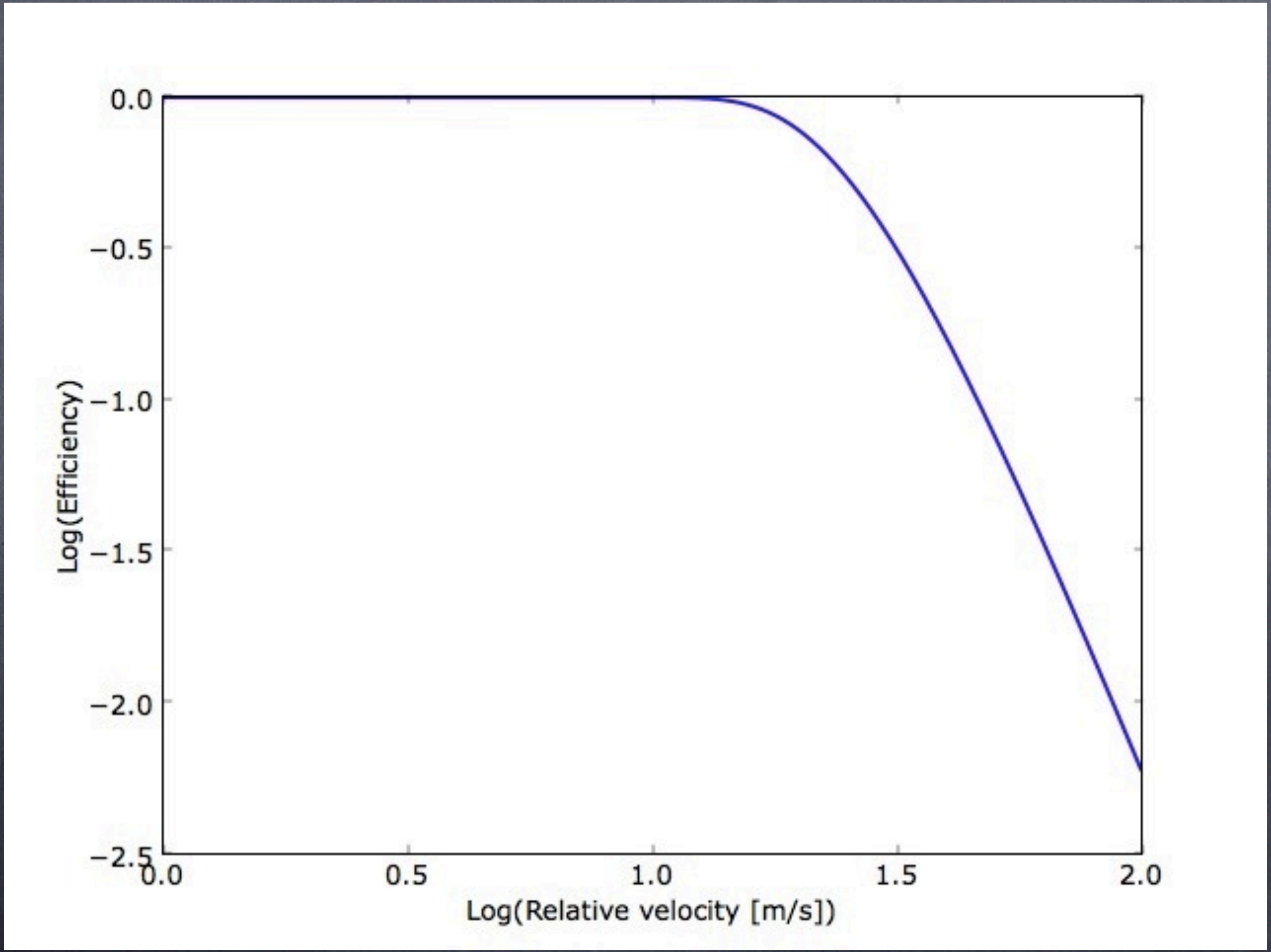
Coagulation
Fragmentation



Tail model

Coagulation

Fragmentation

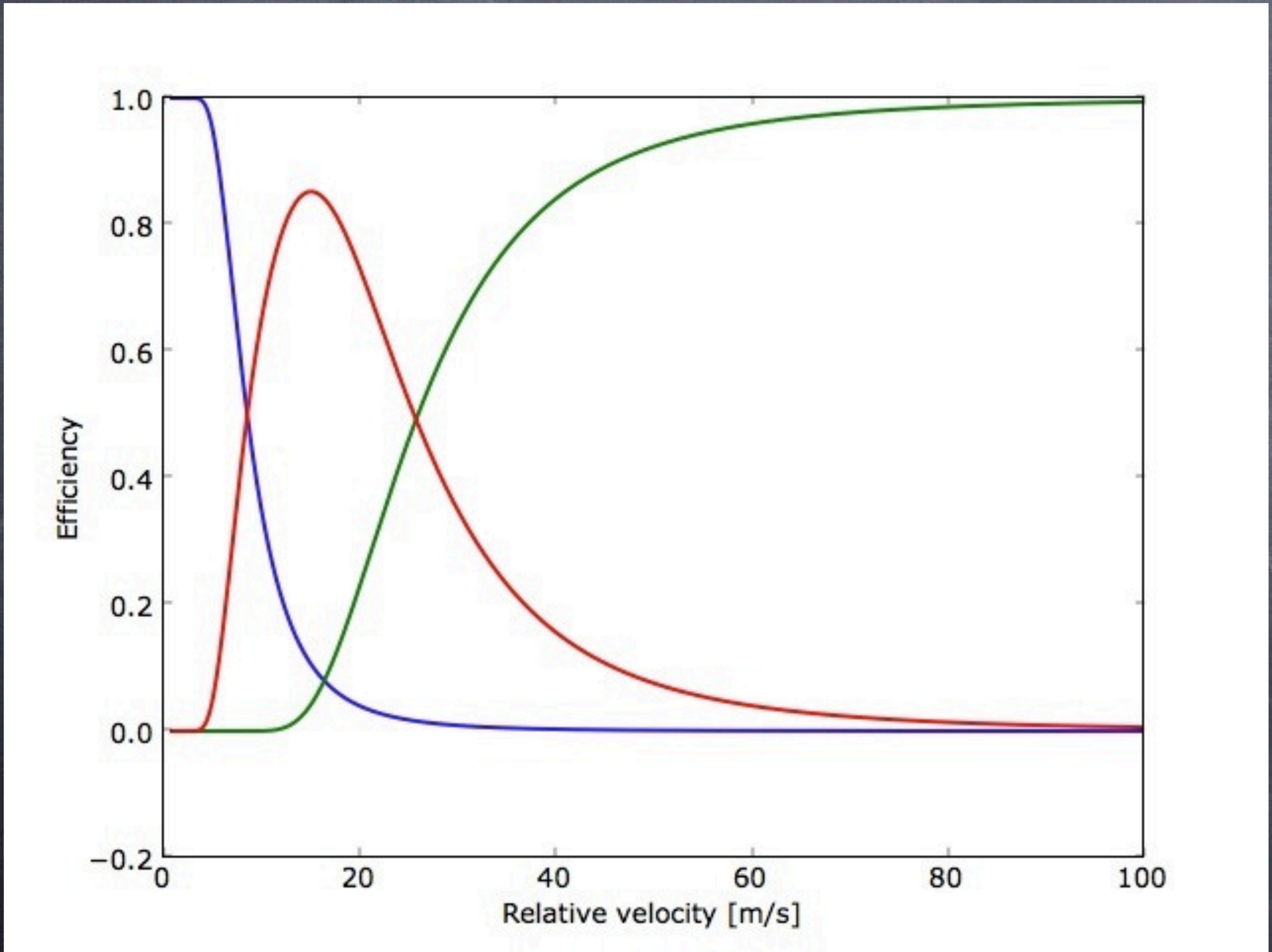


Tail model + Bouncing

Introduction of a bouncing regime:

V_{cirt}(coag) = 10.0 m/s

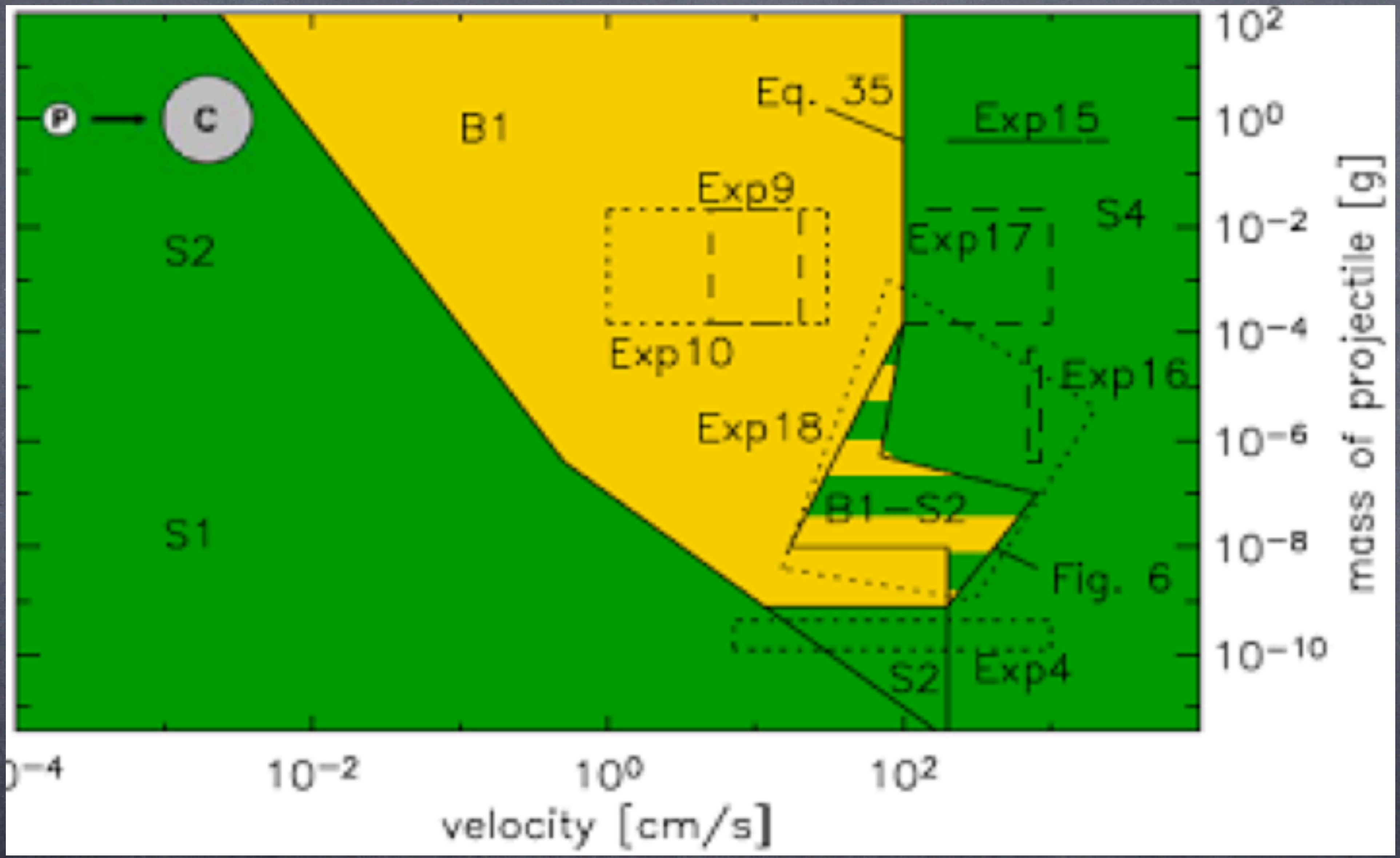
V_{crit}(fragm) = 30.0 m/s



Coagulation
Fragmentation
Bouncing

Tail model + II Coagulation

Introduction of a <u>second coagulation</u> regime, for $(s_i/s_j) > 100.0$



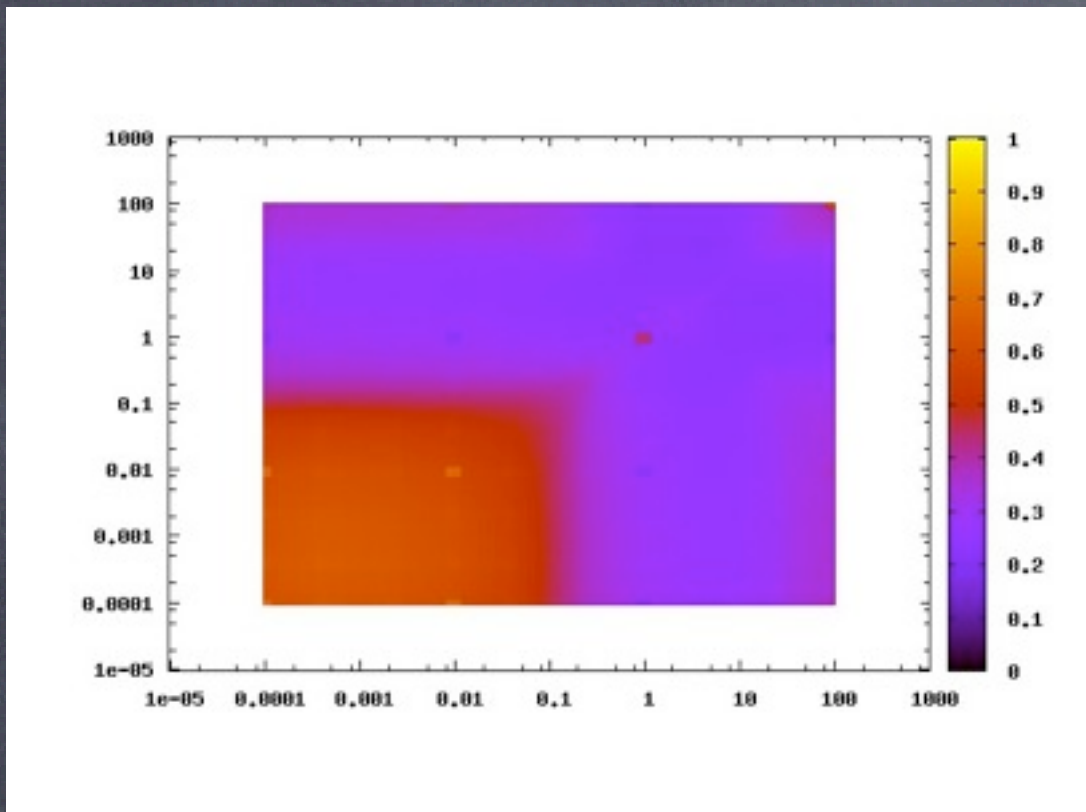
Coagulation

Bouncing

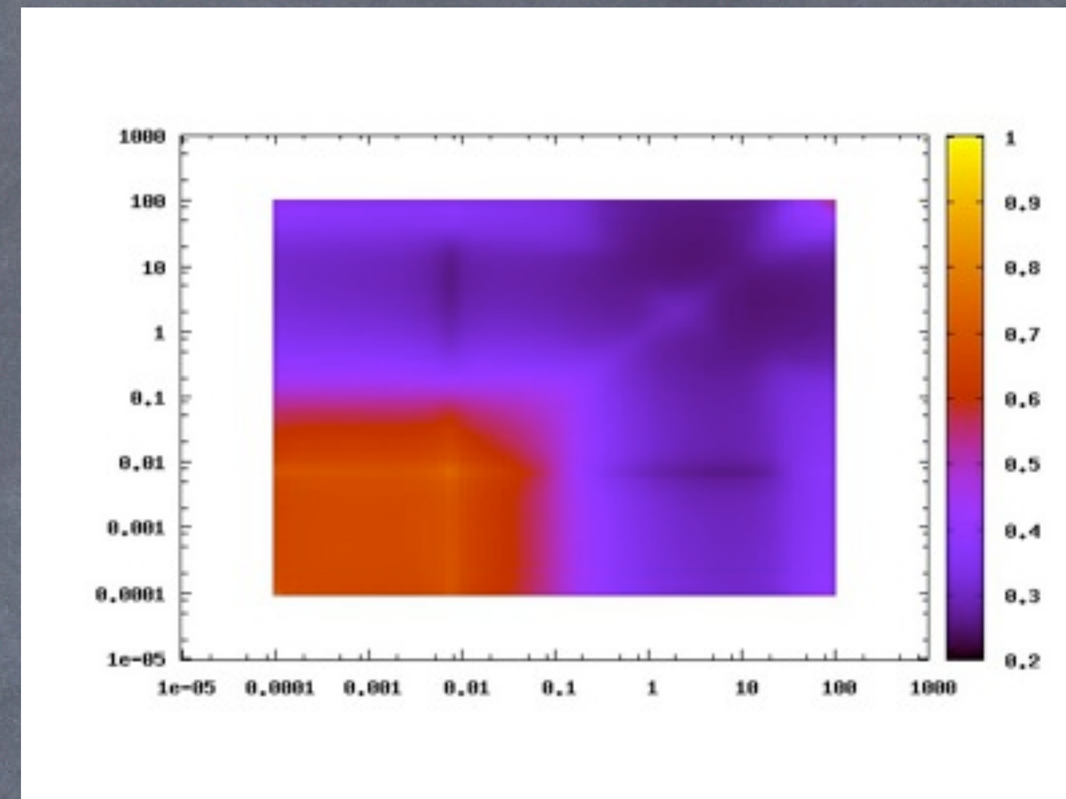
(Blum, 2010)

Tail models: coagulation probabilities

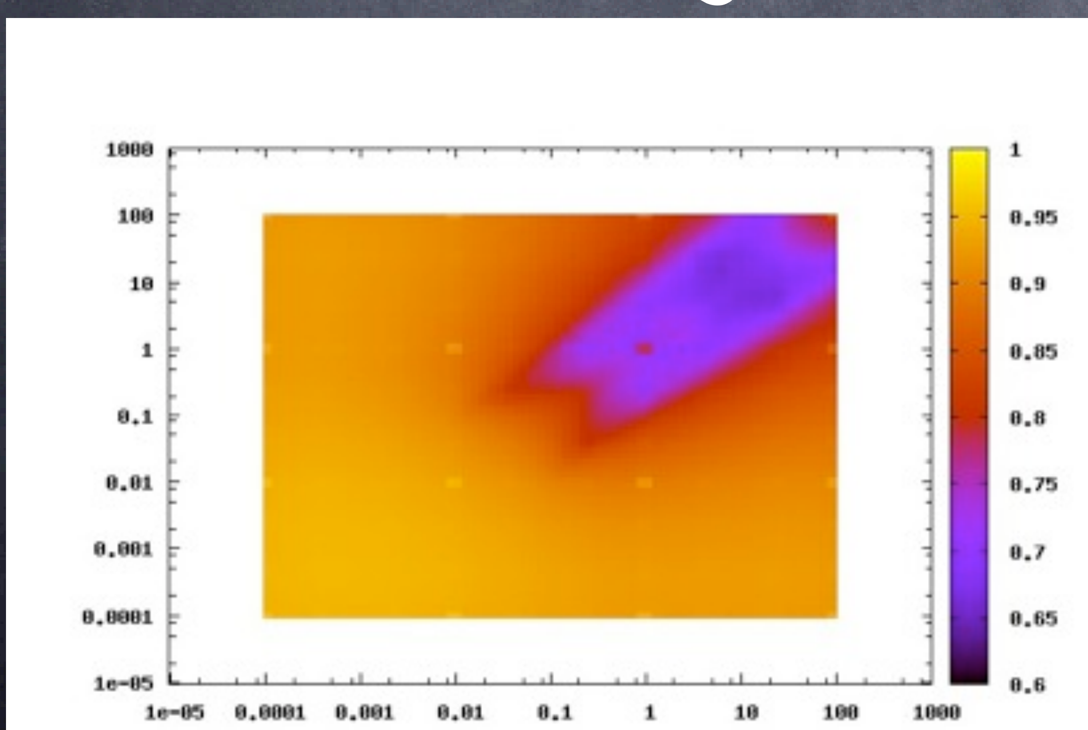
Tail



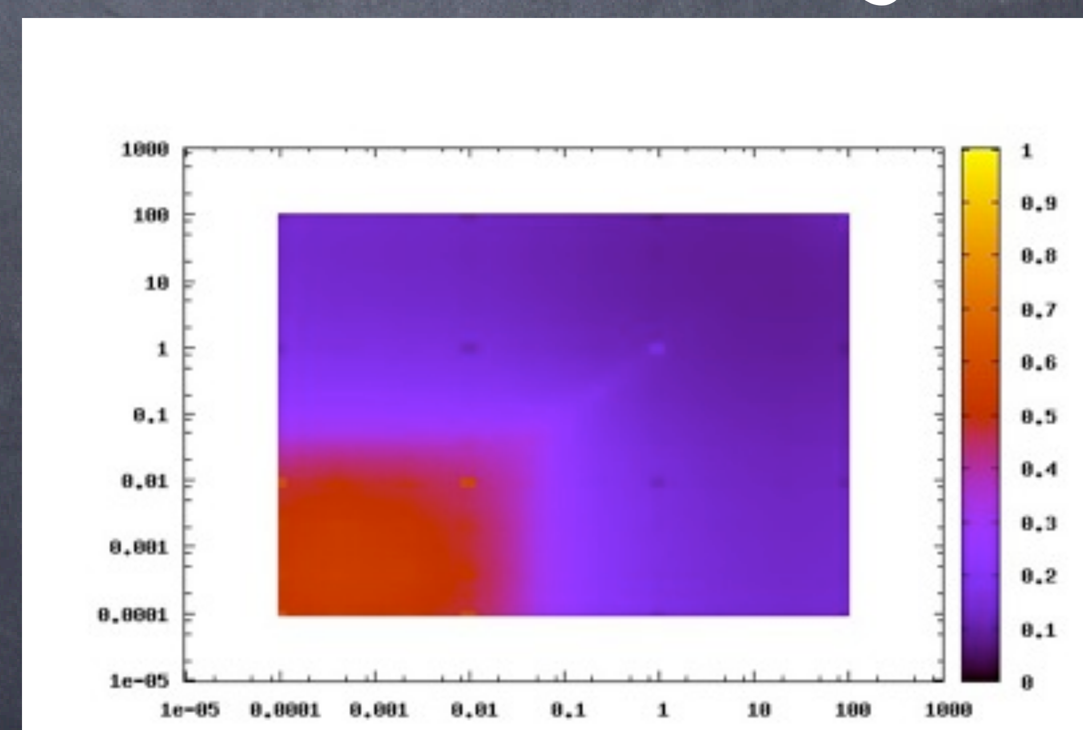
Tail + Porosity



Tail + II Coagulation

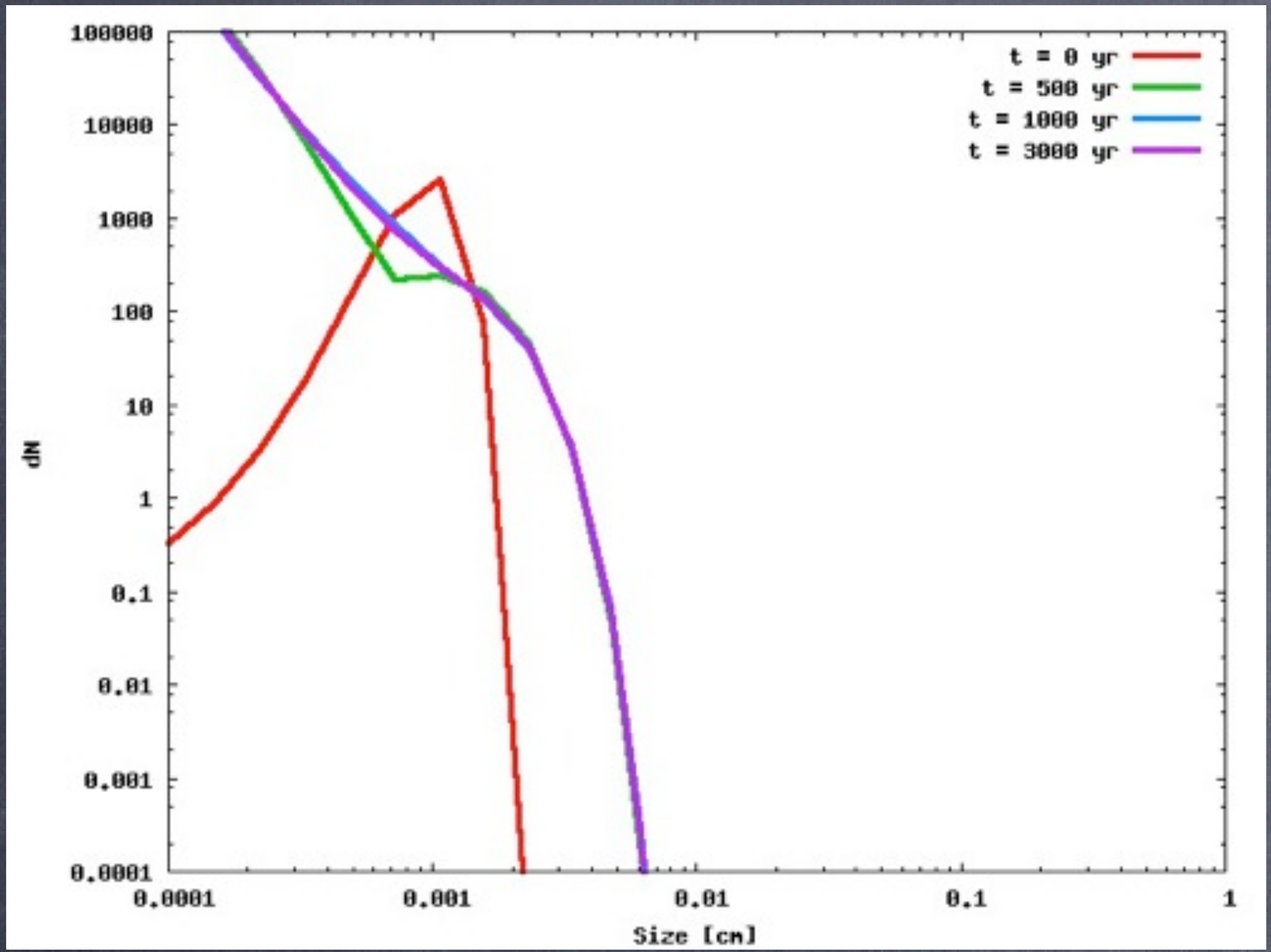


Tail + Bouncing

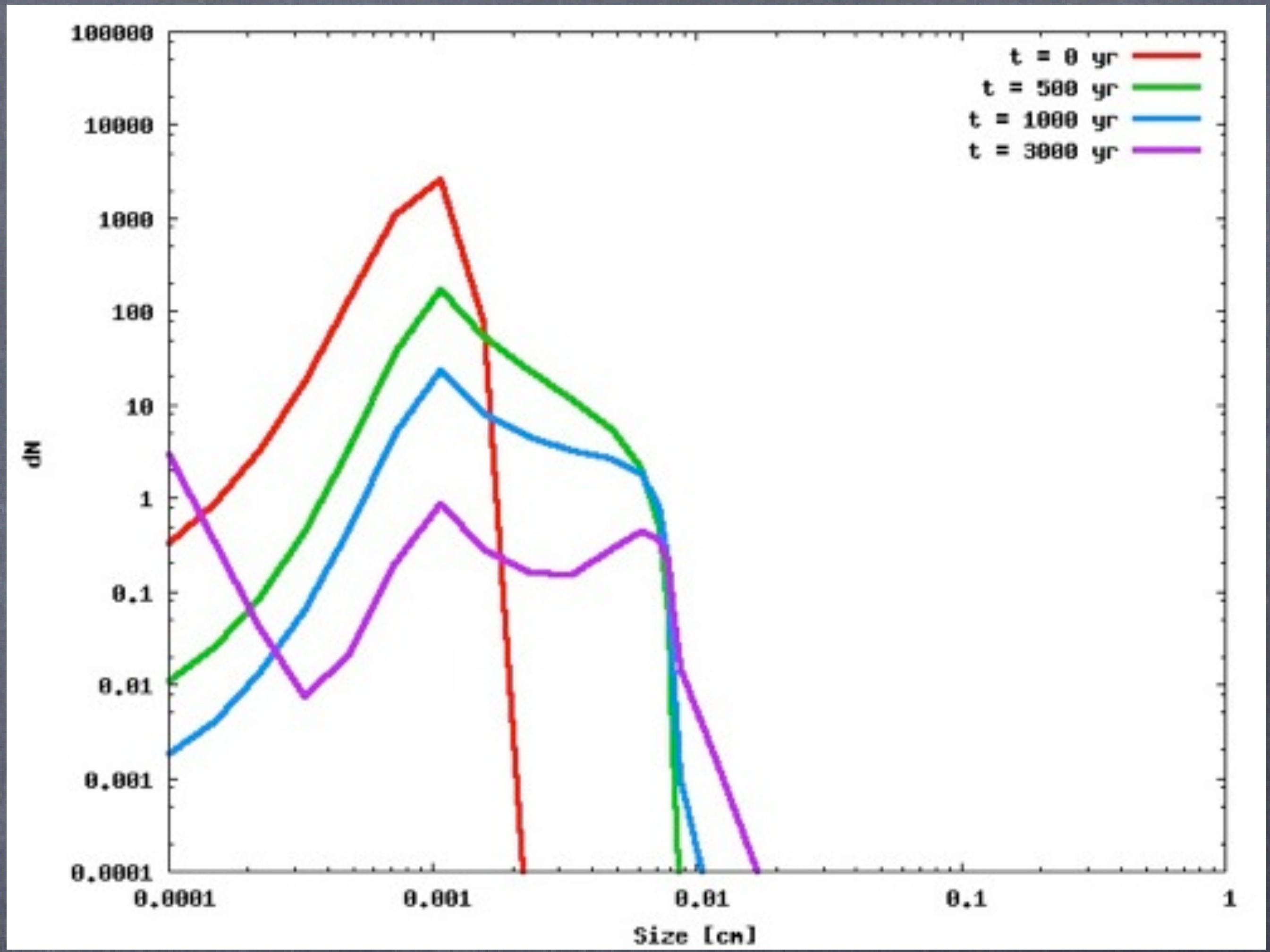


Results

Brauer model



Tail model

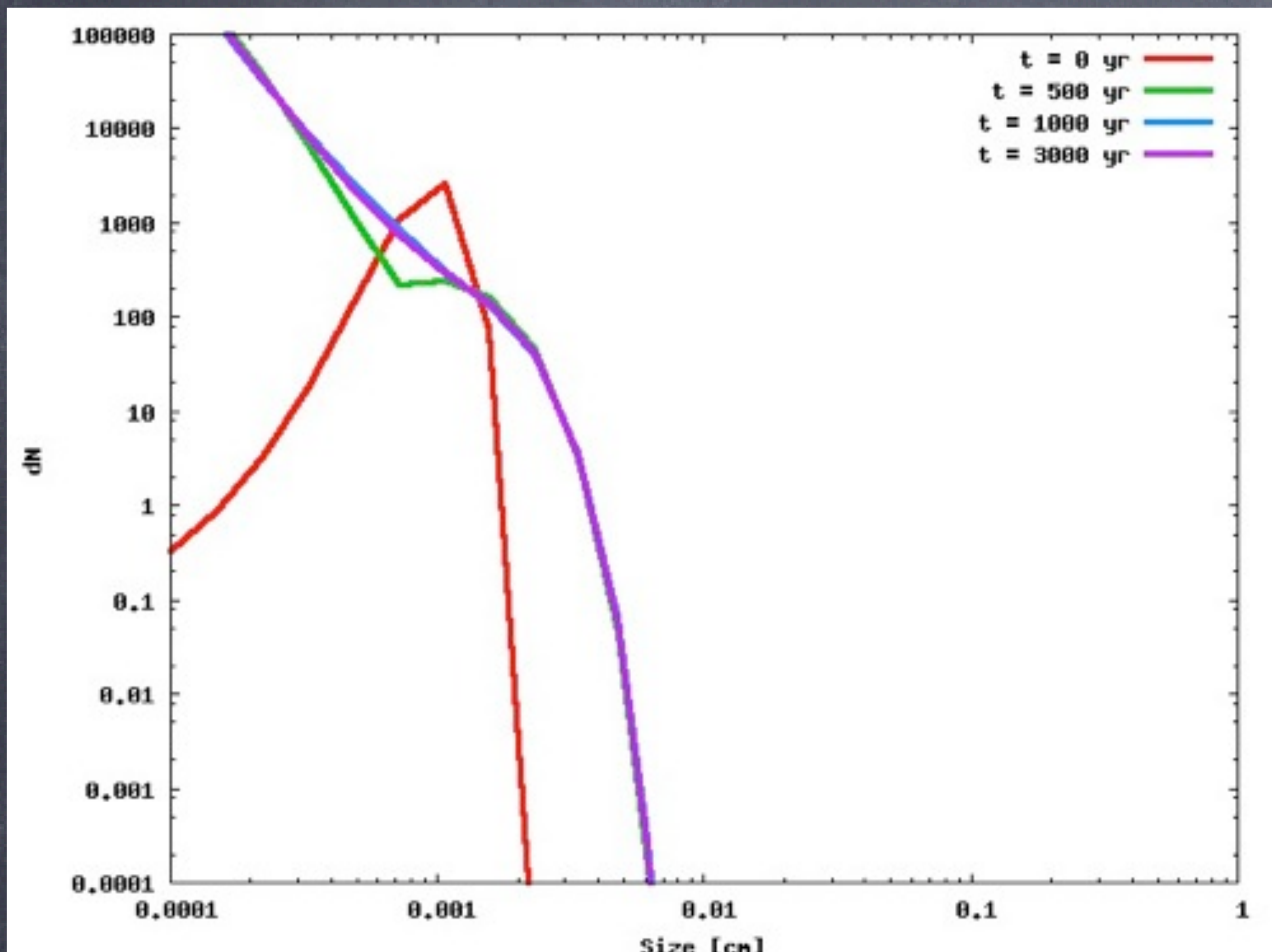


$V_{crit}(fragm) = V_{crit}(coag) = 30$ m/s

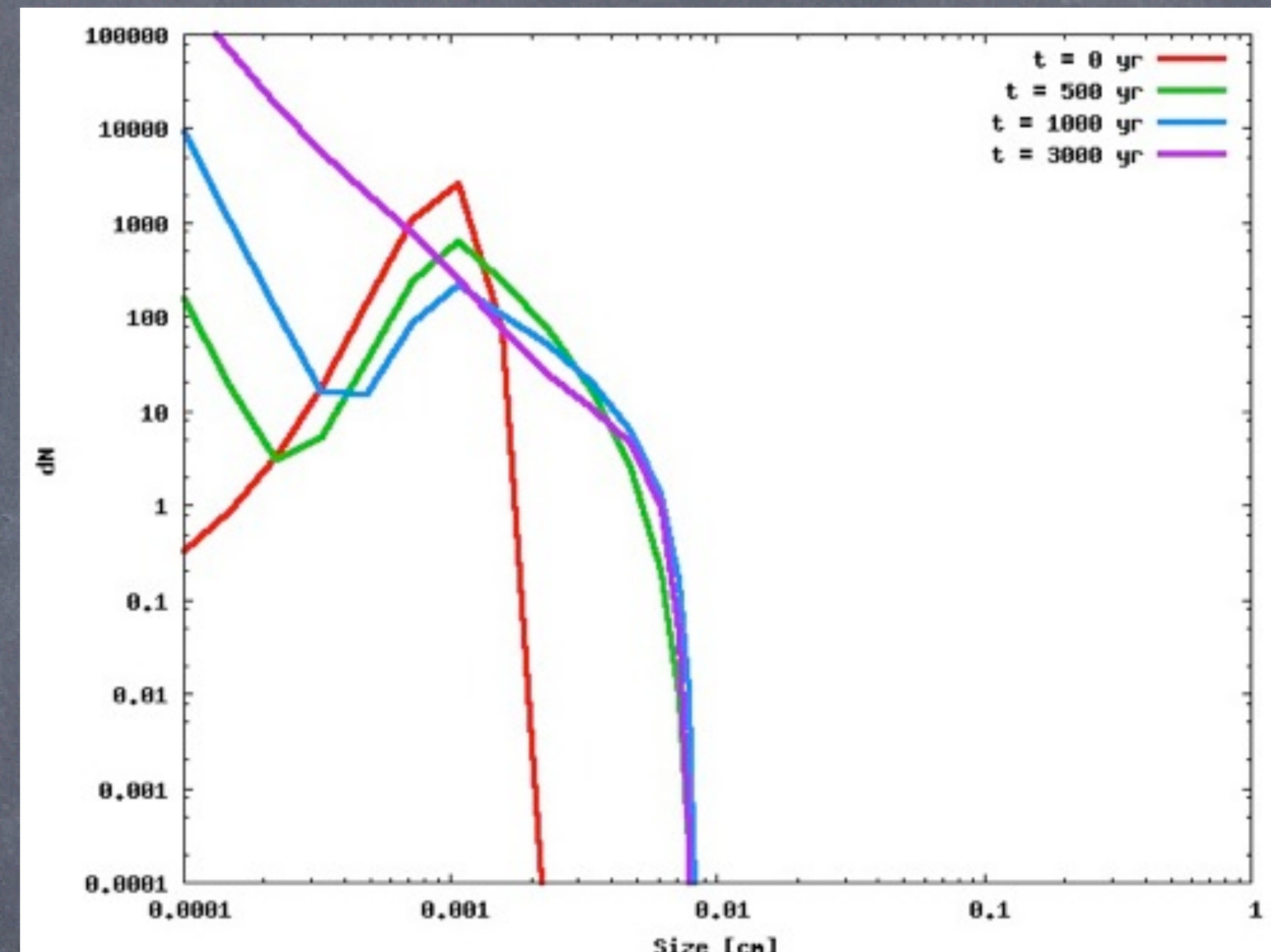
dN = # particles in a (0.001 AU) box

Results

Brauer

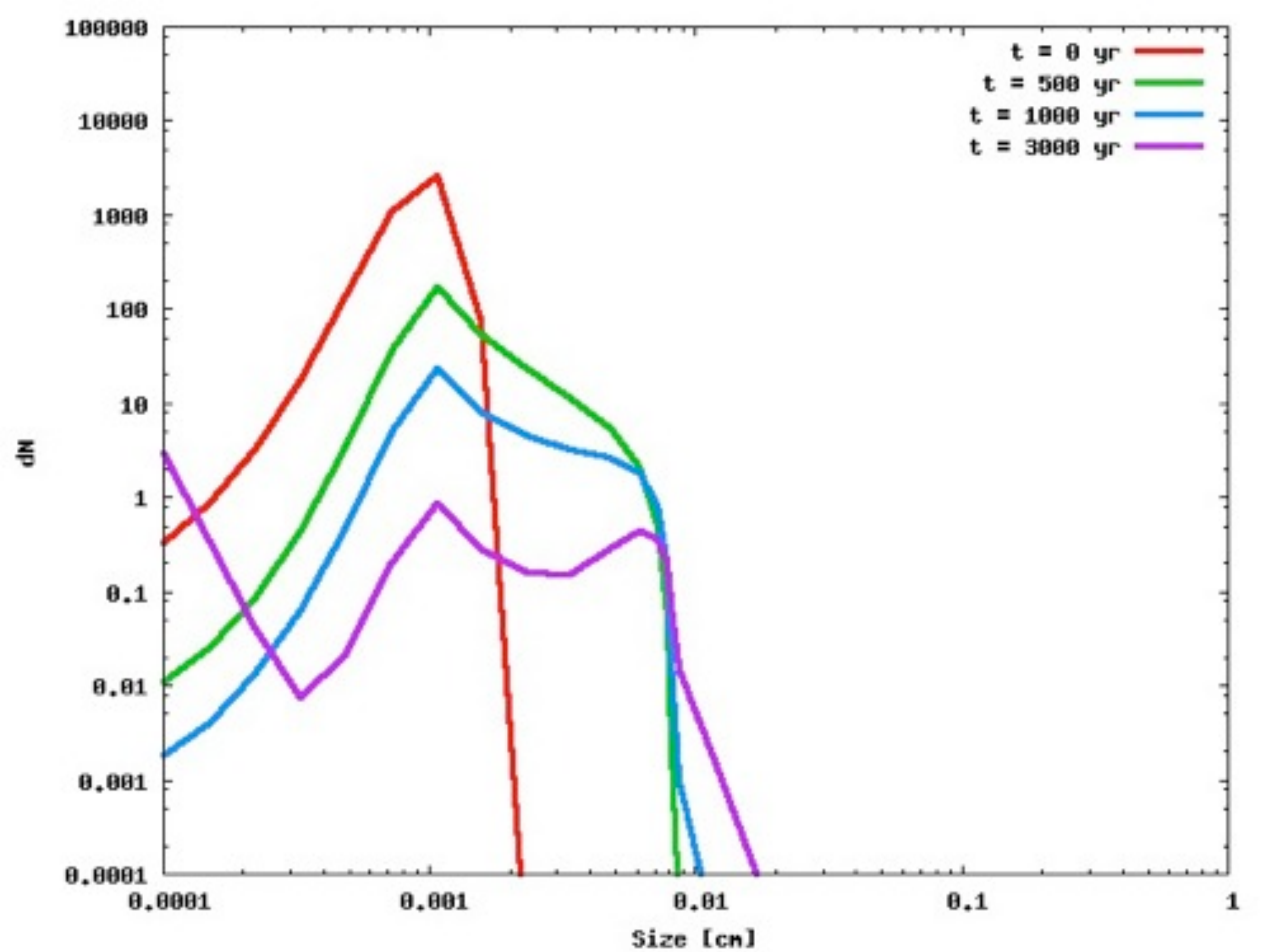


Brauer + porosity

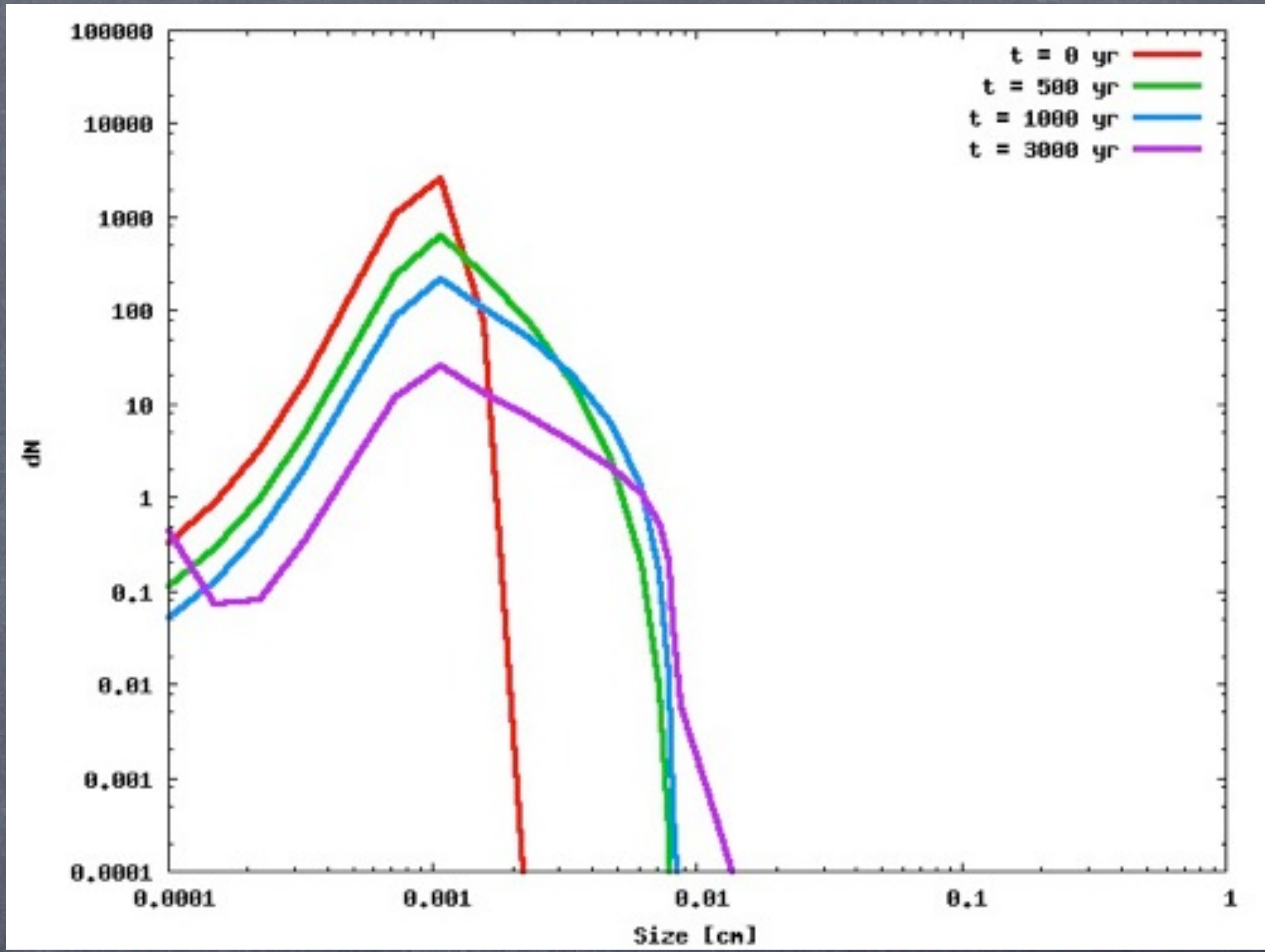


Results

Tail

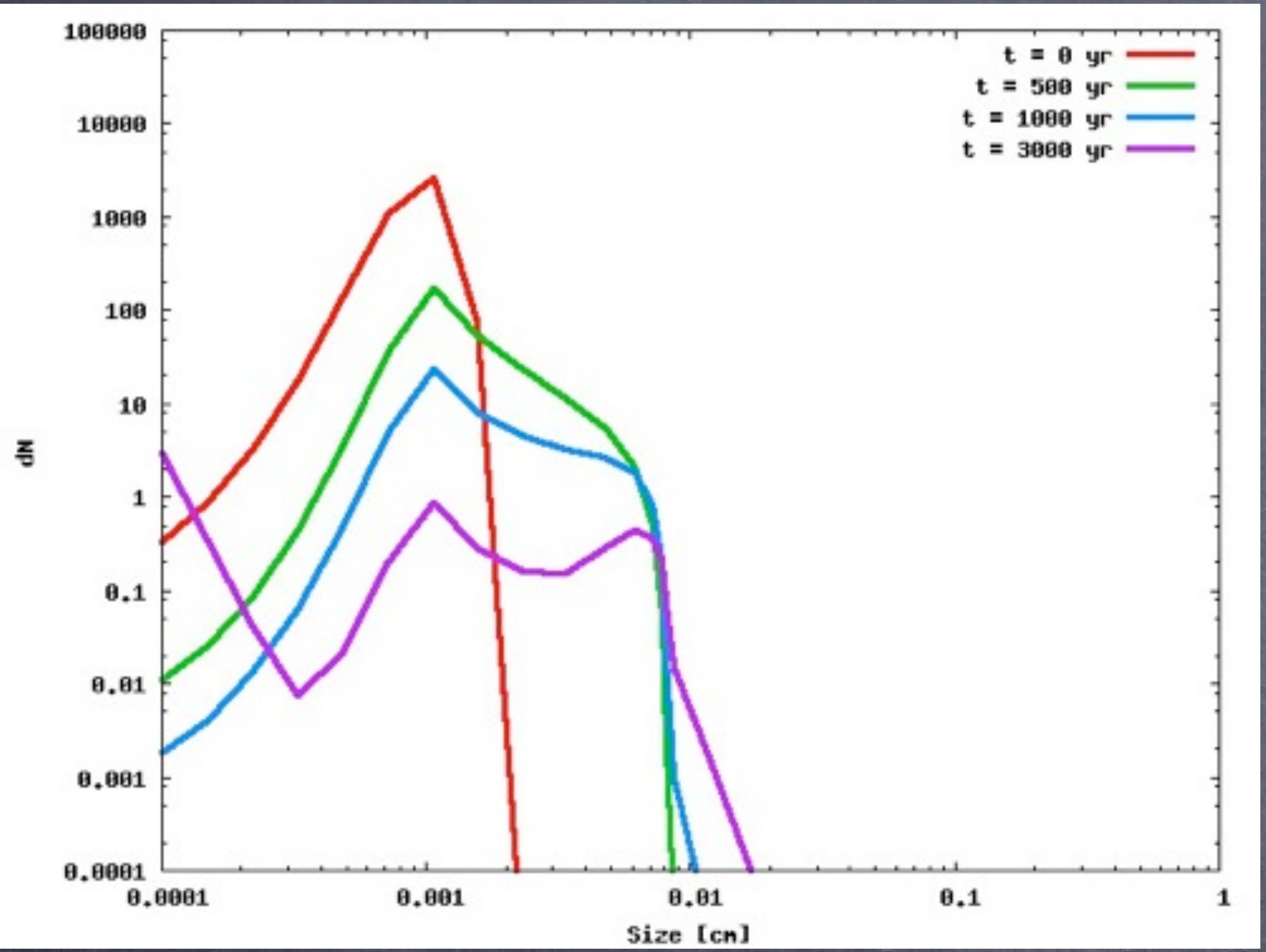


Tail + porosity



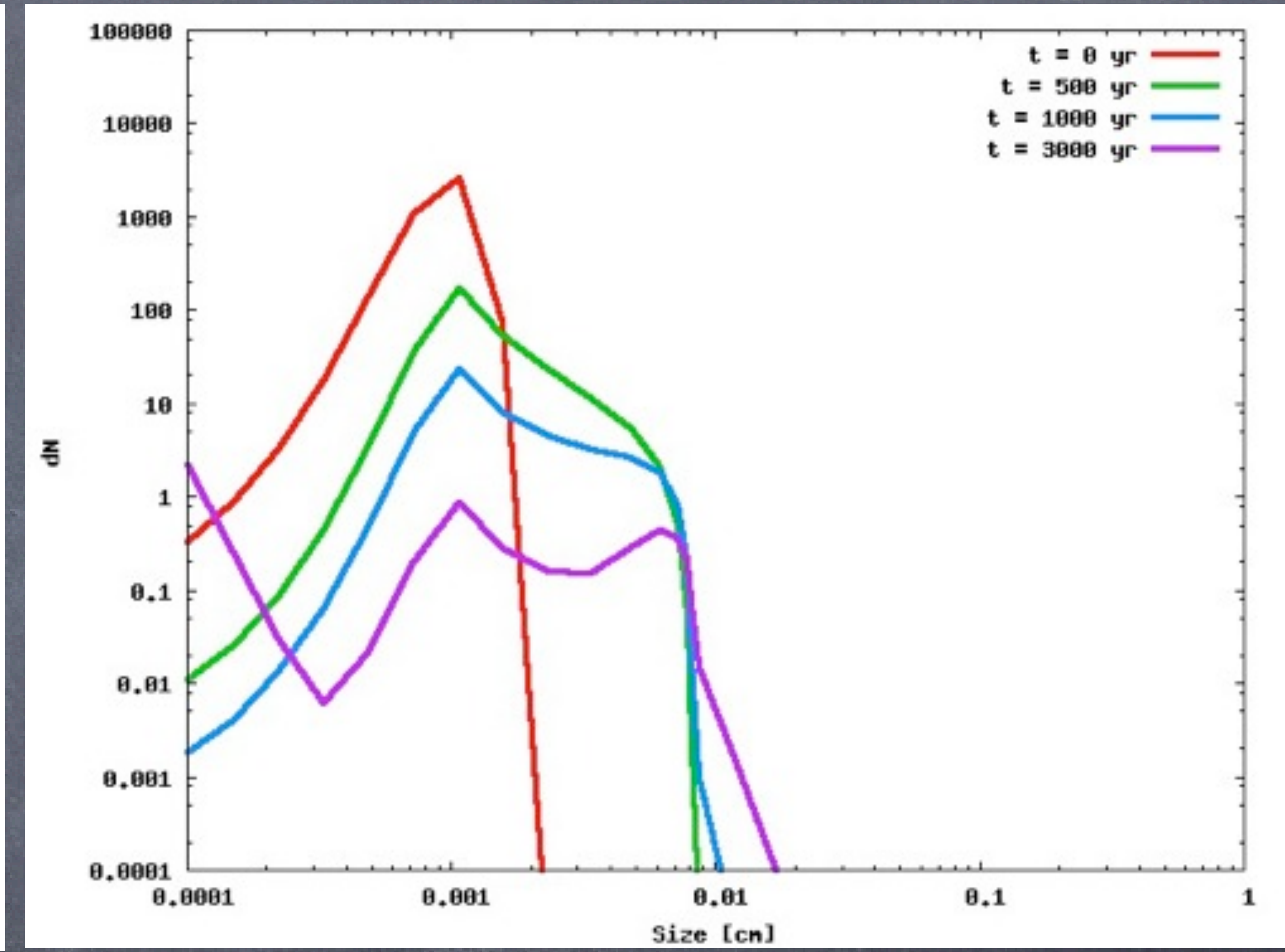
Results

Tail model



V_{crit}(fragm) = V_{crit}(coag) = 30 m/s

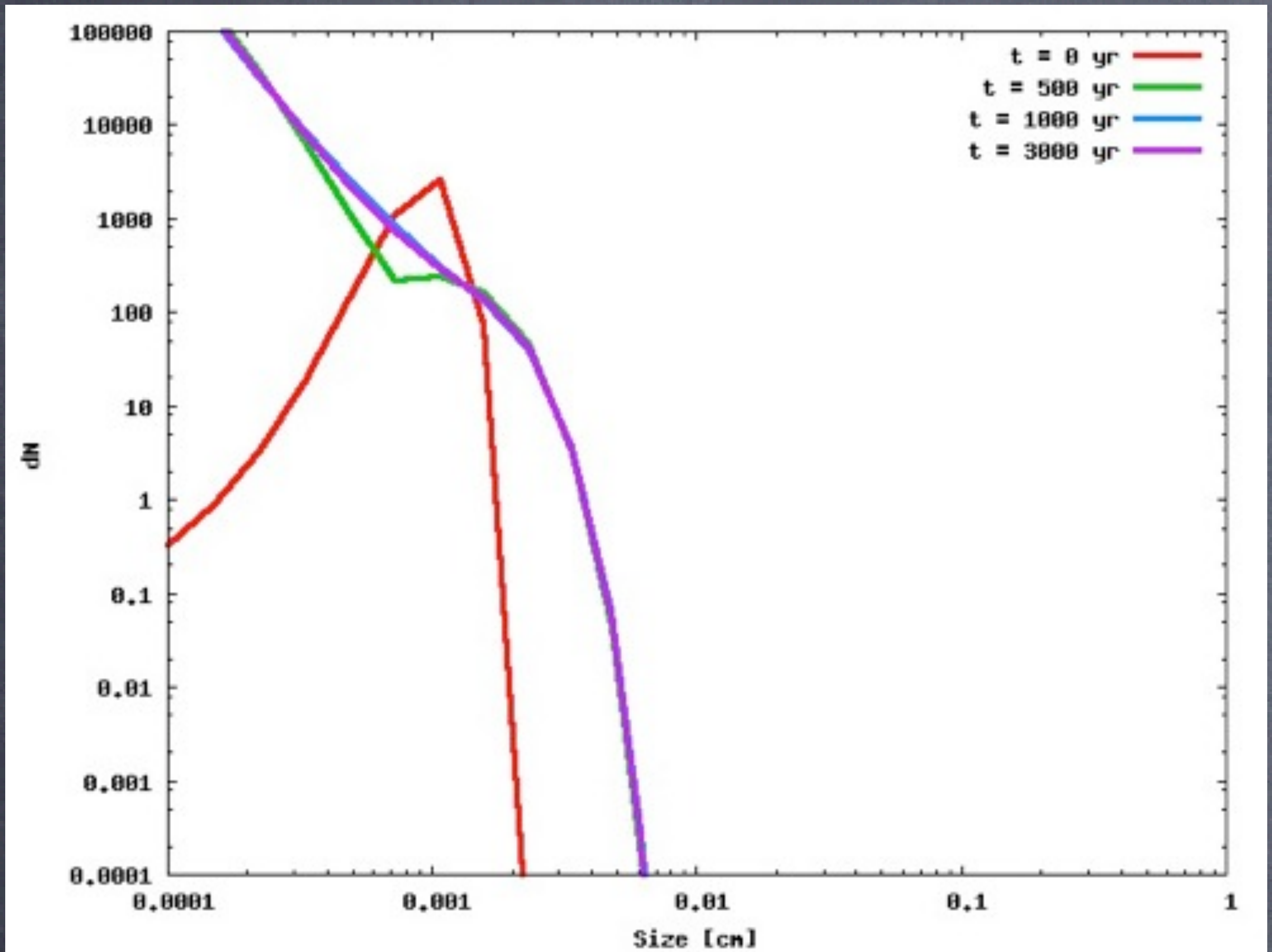
Tail + bouncing



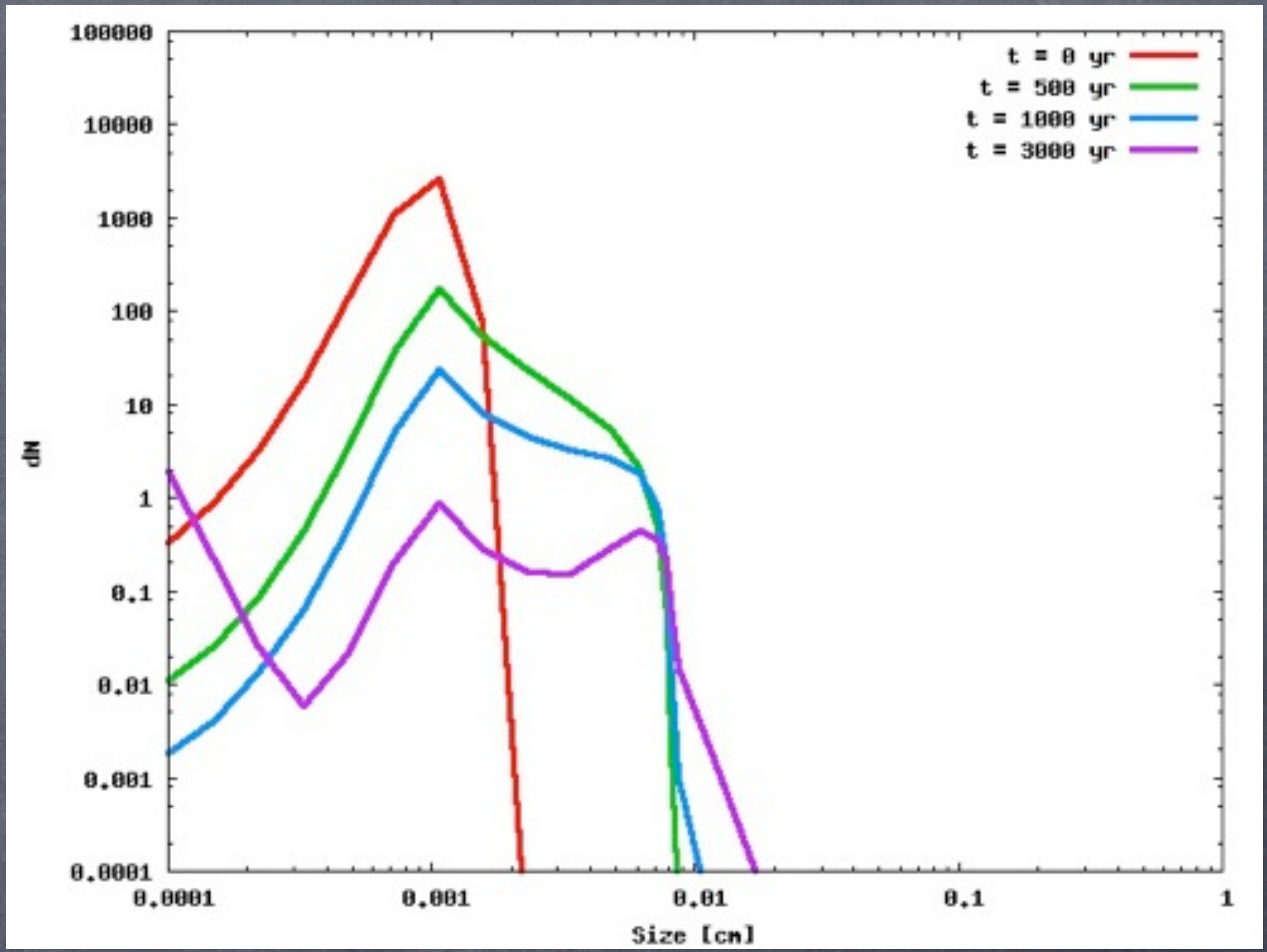
V_{crit}(coag) = 10 m/s
V_{crit}(frag) = 30 m/s

Results

Brauer + II coag

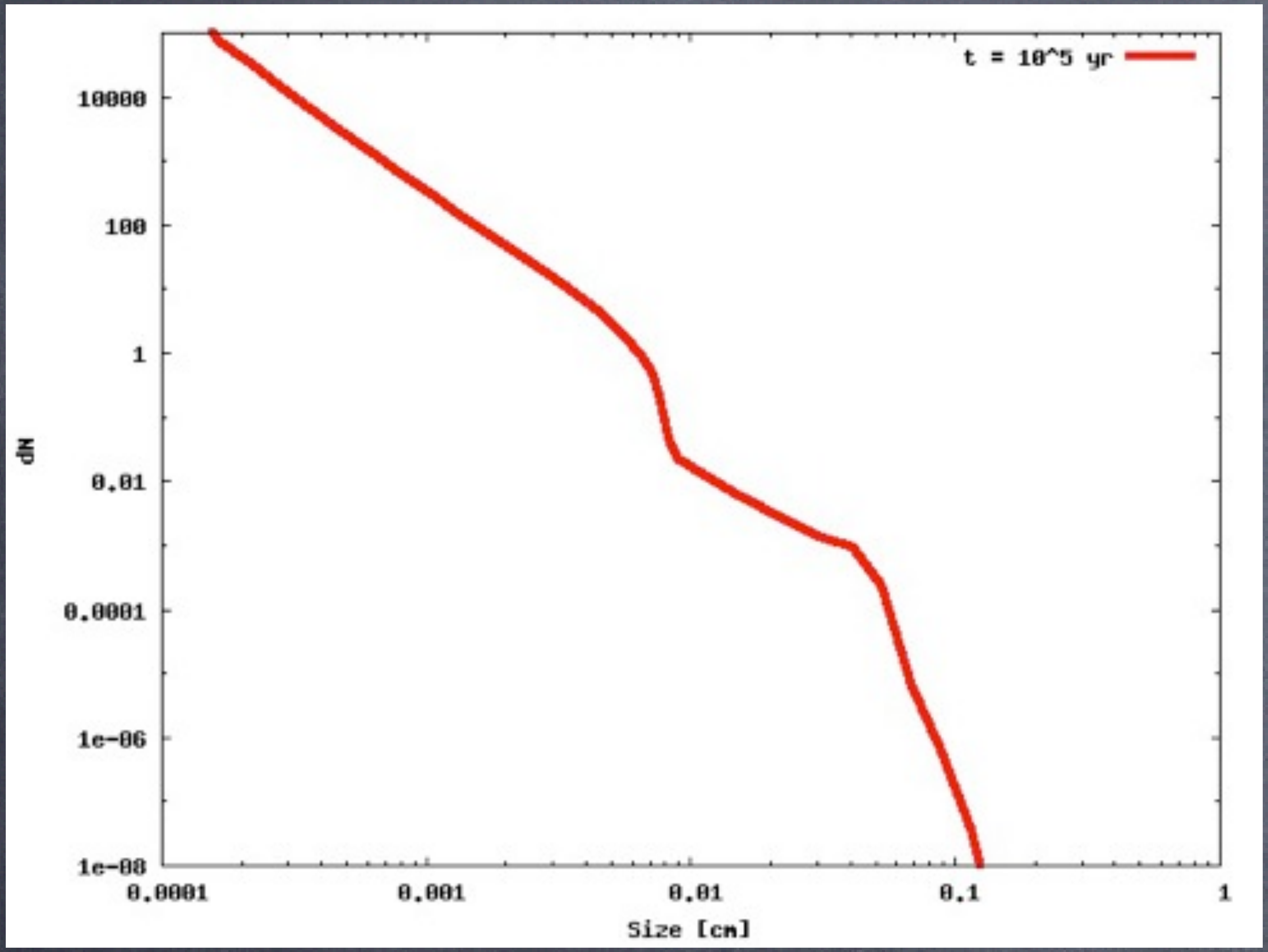


Tail + II coag

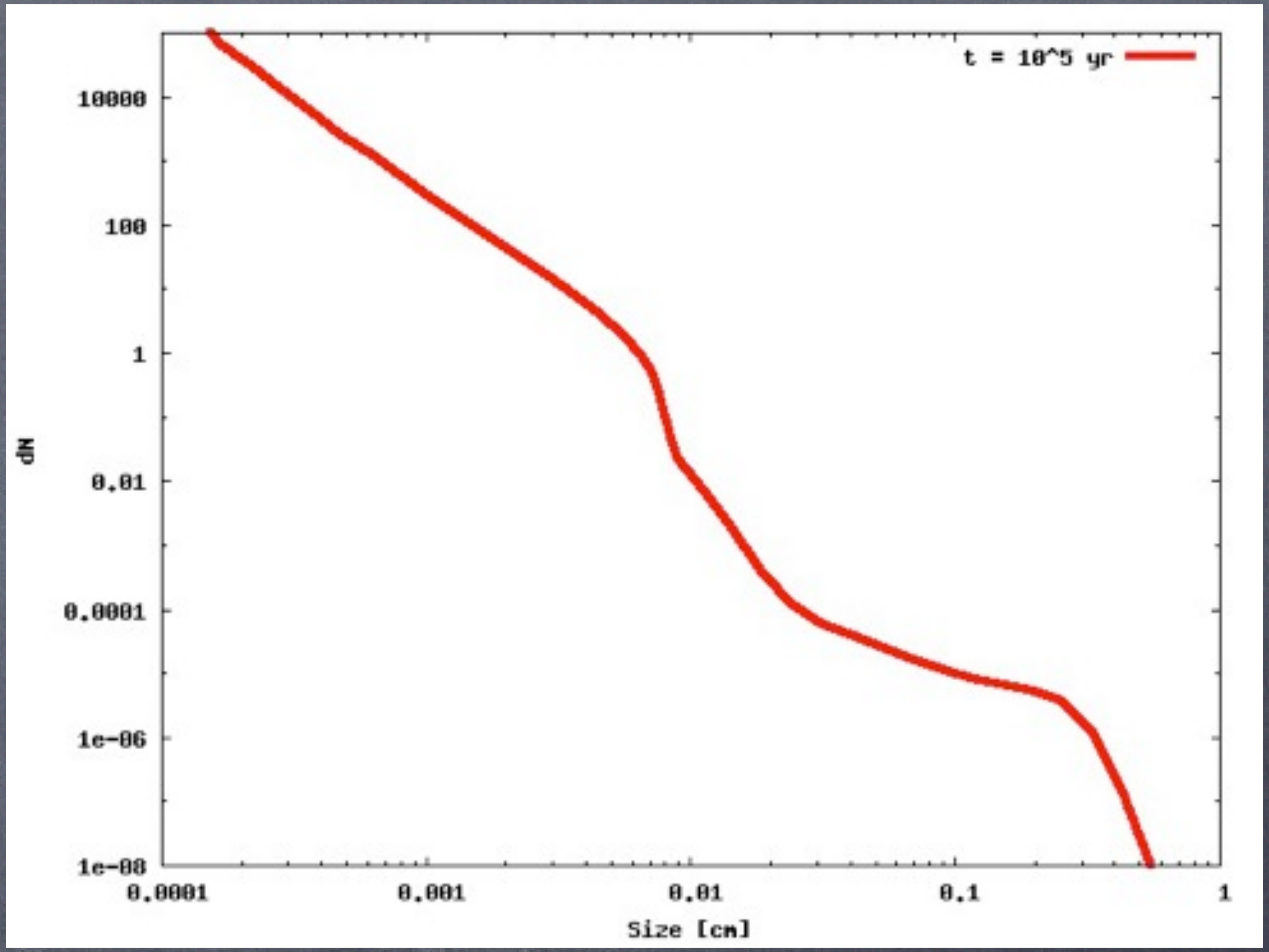


Results

Best-case scenario: Tail + porosity + II coag (size ratio = 10)



V_{crit} = 30 m/s



V_{crit} = 100 m/s

Conclusion

- Brauer model: equilibrium in a few 100s years
- Tail model: overcome critical size
- Porosity: increase growth for Brauer / Tail model
- Bouncing region: no effect
- Second coagulation region: no effects (for ratio = 100), increase in max size (for ratio = 10)
- Best case scenario: formation of mm-size grains

Future work

- Collisional fusion (Wettlaufer 2011)
- Turbulence models (M. Rast's talk)
- Shift in critical velocities (size ratio of particles)
- ...

THANKS!!


科维理天文与天体物理研究所
Kavli Institute for Astronomy and Astrophysics