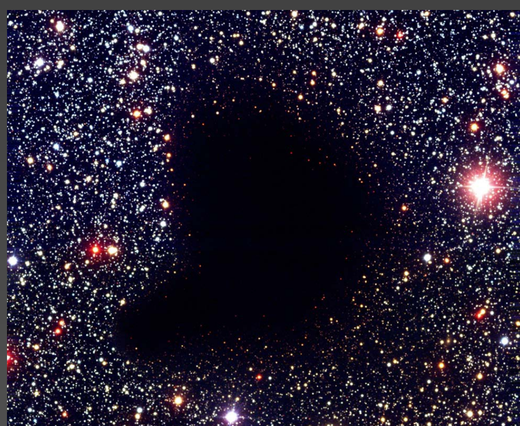
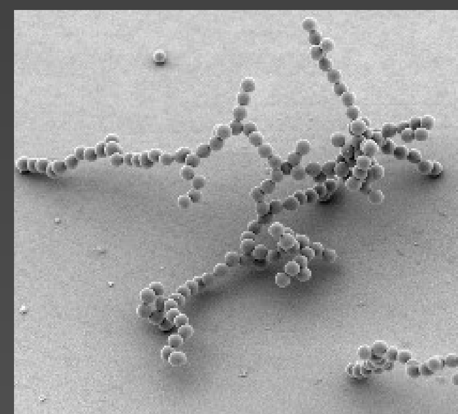
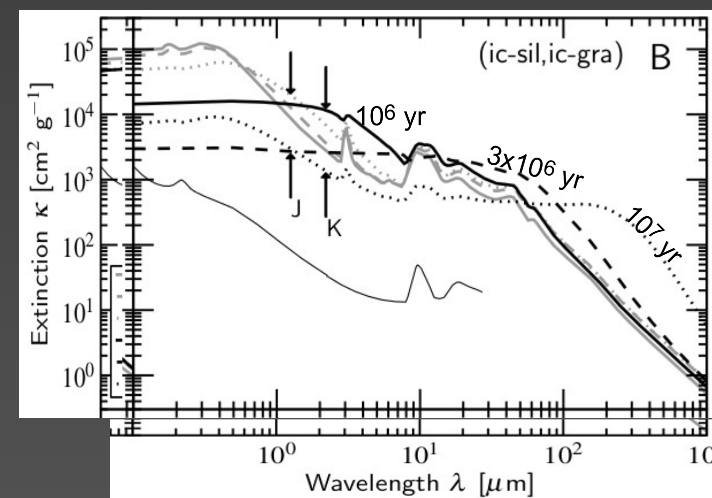
Coagulation and Fragmentation of Dust in Molecular Cloud cores

[Ormel et al. 2009, 2011]







Chris Ormel
Hubble fellow, UC Berkeley

Collaborators:
Dominik Paszun, Michiel Min, Carsten Dominik (U. of Amsterdam)
Xander Tielens (U. of Leiden)

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2. Numerical calculations dust growth
   - Ormel+(2009,2011)
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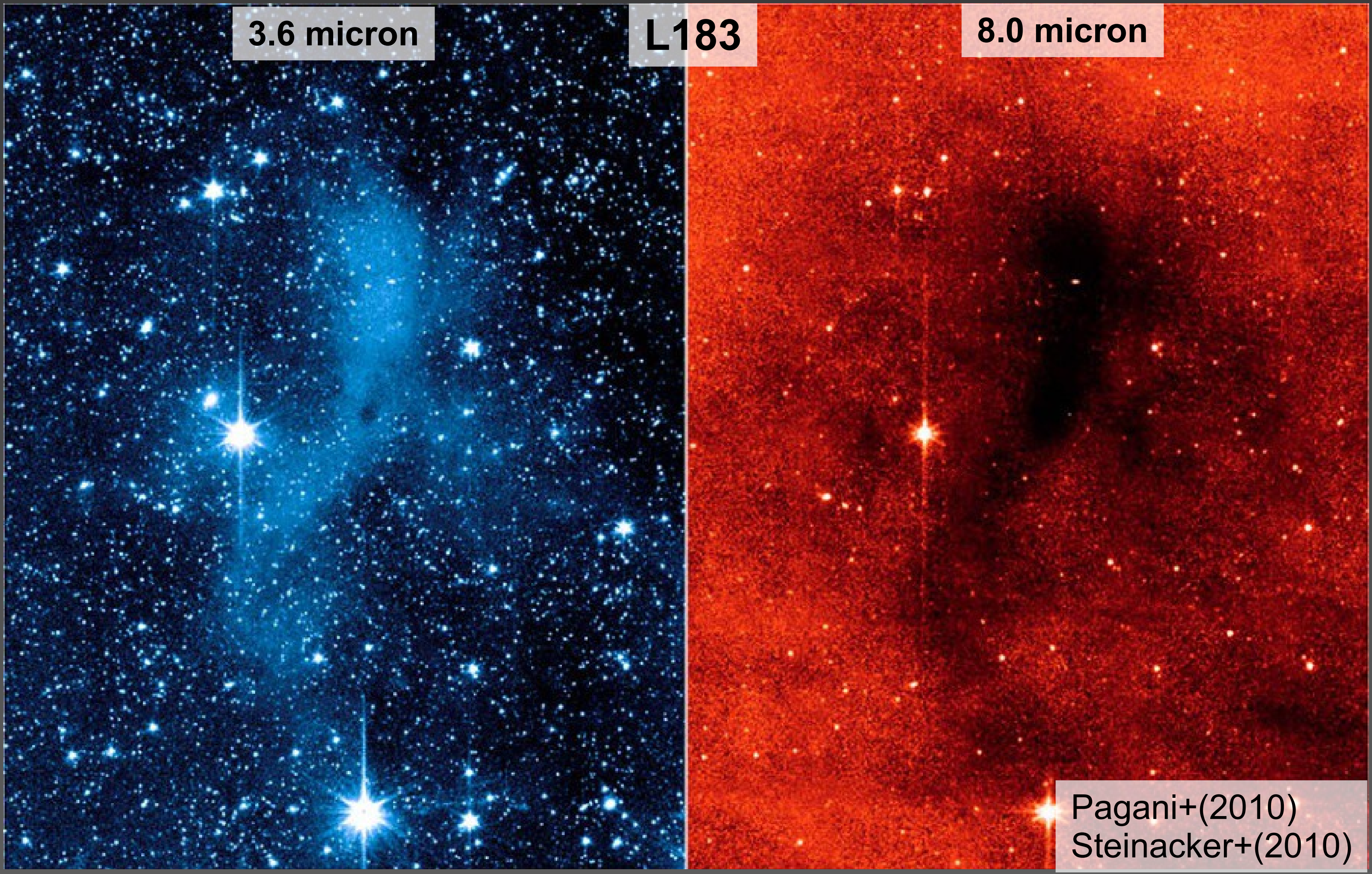
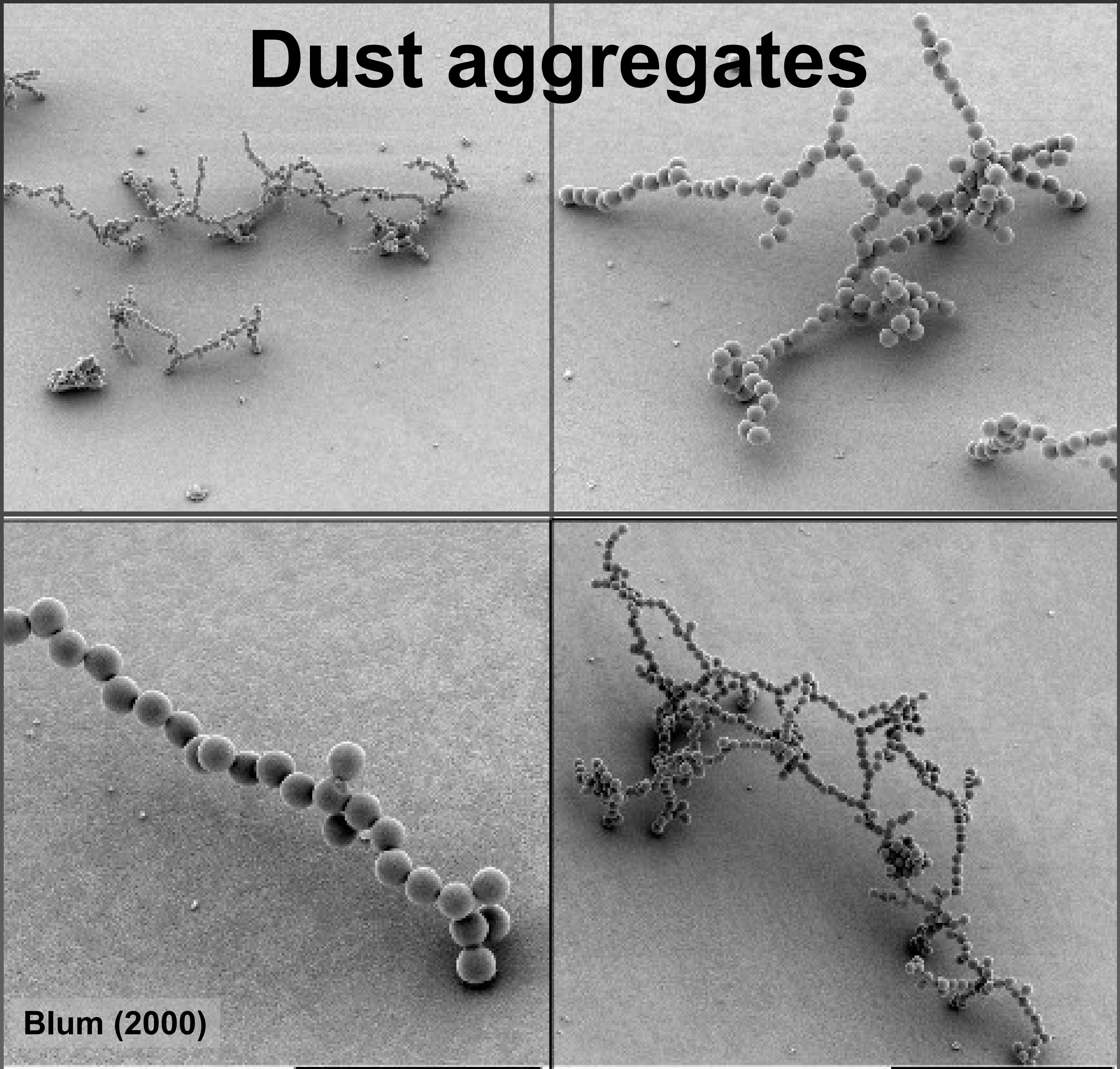
Obsv. evidence grain growth



Core-shine

Dust aggregates



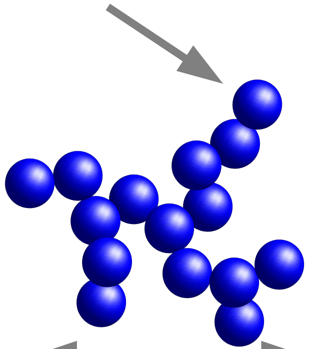
Terminology

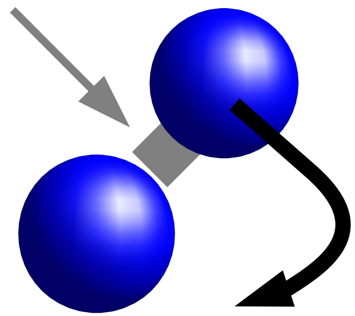
Condensation, Coagulation, Fragmentation

- Condensation = Ice mantle formation
- Coagulation = Aggregation
- Fragmentation = Disaggregation

cf. Hirashita (2012)

Physics of dust aggregate collisions





E_{break}, E_{roll} = f(material prop.)

E = Collision energy = f(mass, vel)

<u>Dominik & Tielens (1997) collision recipe:</u>

$E < E_{break}$; E_{roll} :sticking w/o compaction → **fractal growth**

$E > E_{roll}$:**restructuring**

$E >> N\ E_{roll}$:**fragmentation**

<u>For rurther update/refinements see:</u>

Ossenkopf (1993); Blum & Wurm (2008); Paszun & Dominik (2008--2009); Wada+(2008--2011); Okuzumi 2009; Güttler+(2009); Seizinger+(2012)

10 cm/s, silicates

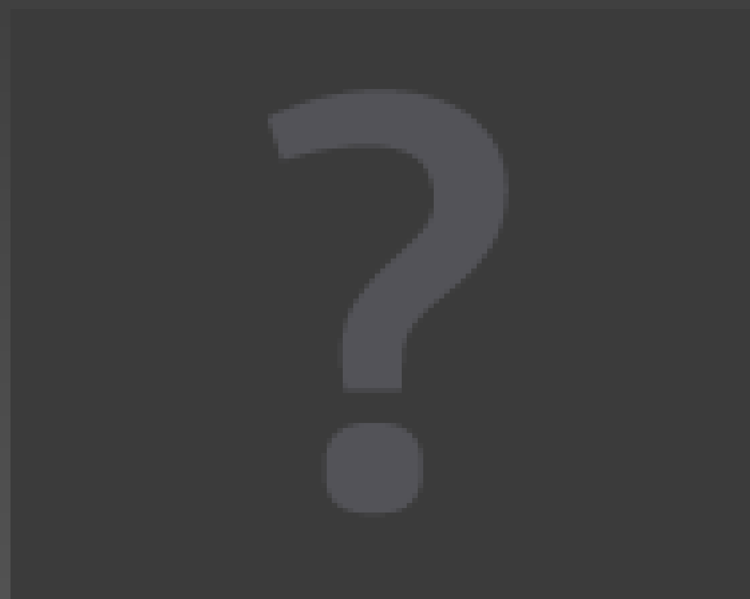
1 m/s, silicates

Velocity (collision energy) matters!

2 m/s, fluffy

Internal structure (porosity) matters too

8 m/s, ice



Composition matters!

Grain growth calculations [Ormel+2009]

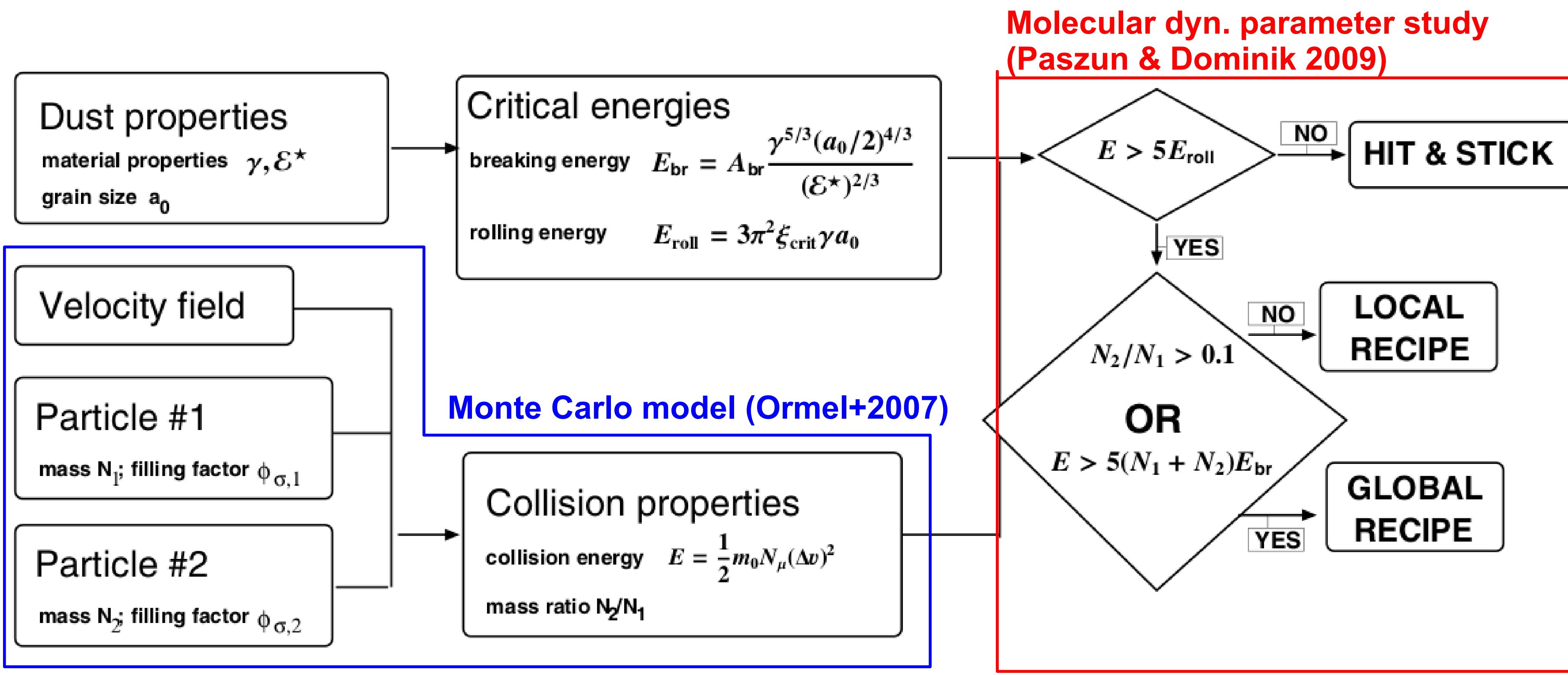
Model assumptions:

- Turbulent motions (subsonic) dominate
- Marginally-stable: $L = L_J$ and $V = c_s$
- Single grain size (0.1um)
- Homogeneous cloud

$$\Delta v_0 \approx 8.3 \times 10^2 \text{ cm s}^{-1} \left(\frac{a_0}{0.1\ \mu\text{m}}\right)^{1/2} \left(\frac{n}{10^5 \text{ cm}^{-3}}\right)^{-1/4} \left(\frac{T}{10 \text{ K}}\right)^{1/4}.$$

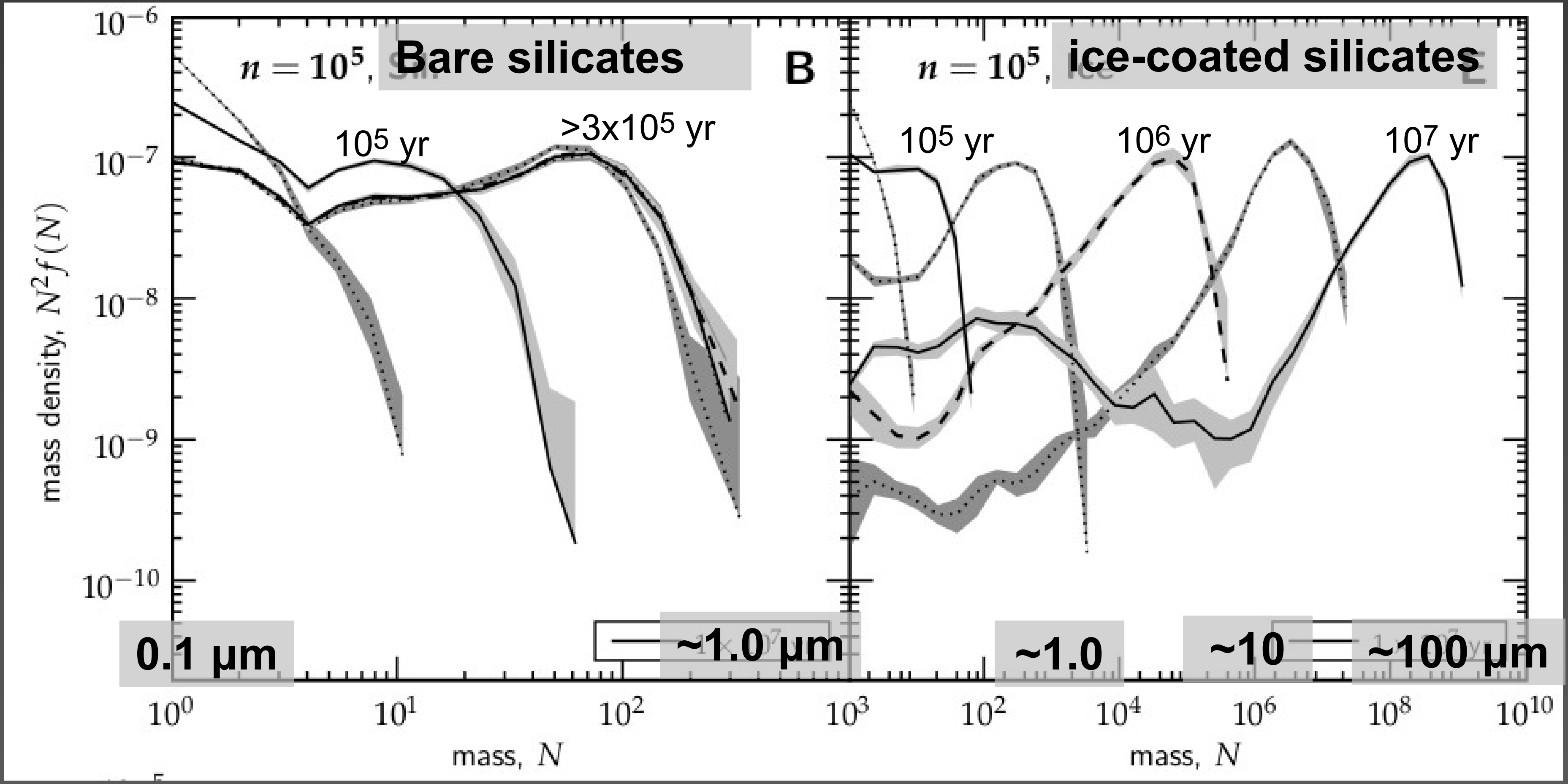
$$t_{\text{coll},0} = \left(8.5 \times 10^4 \text{ yr} \left(\frac{a_0}{0.1\ \mu\text{m}}\right)^{1/2} \left(\frac{n}{10^5 \text{ cm}^{-3}}\right)^{-3/4} \left(\frac{T}{10 \text{ K}}\right)^{-1/4} \right.$$

Simulation setup [Ormel+2009]



Statistical treatment:
Combine *collisional evolution code* (Monte Carlo)
with parameter study of *molecular dynamics*

Results I: size distribution



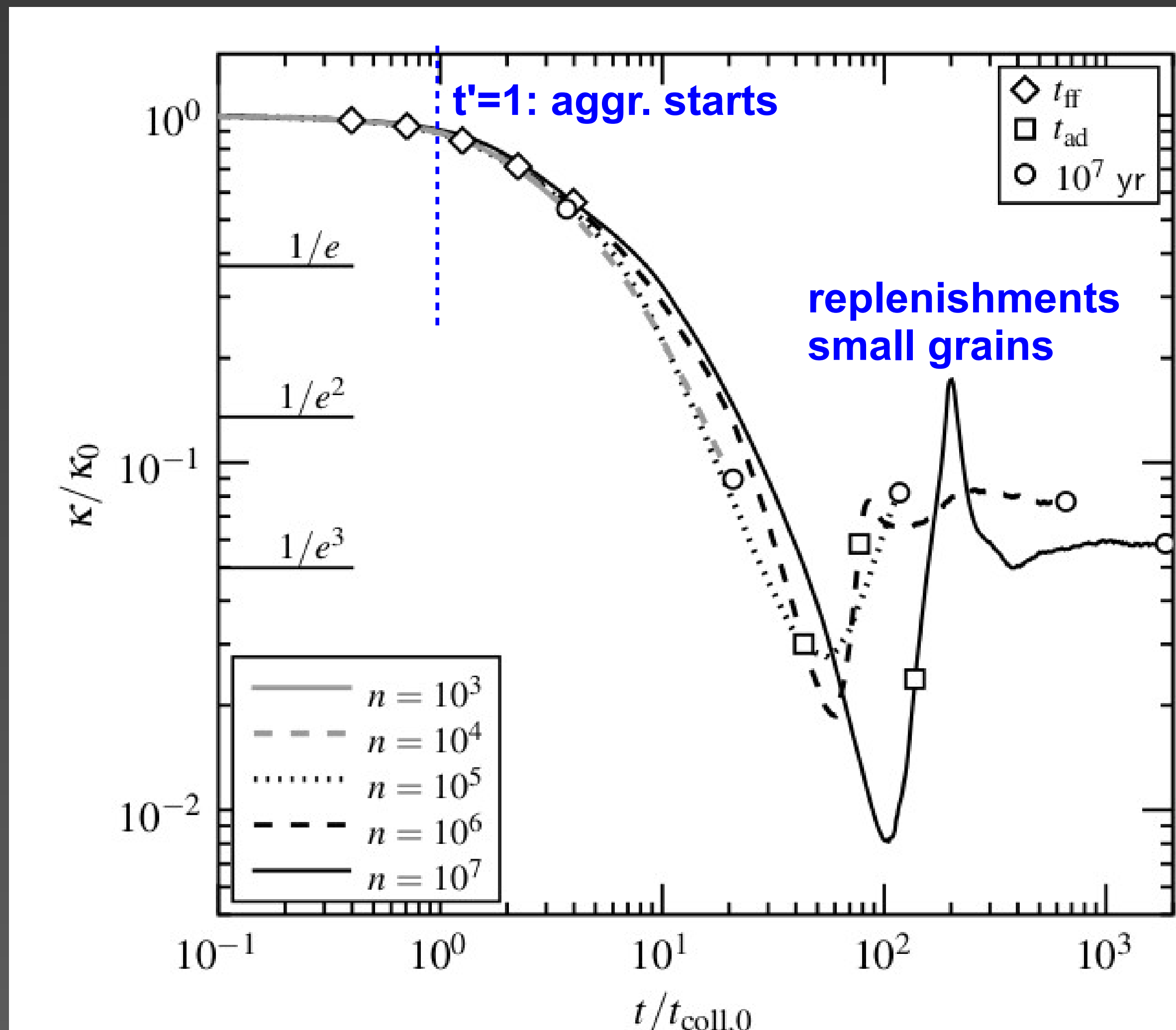
Steady State!
Coagulation balances fragmentation

Significant Growth!
Due to stickiness of ice

Results II: universal scaling

(ice-coated models)

Geometrical opacity [initial ~]



Time [initial collision time]

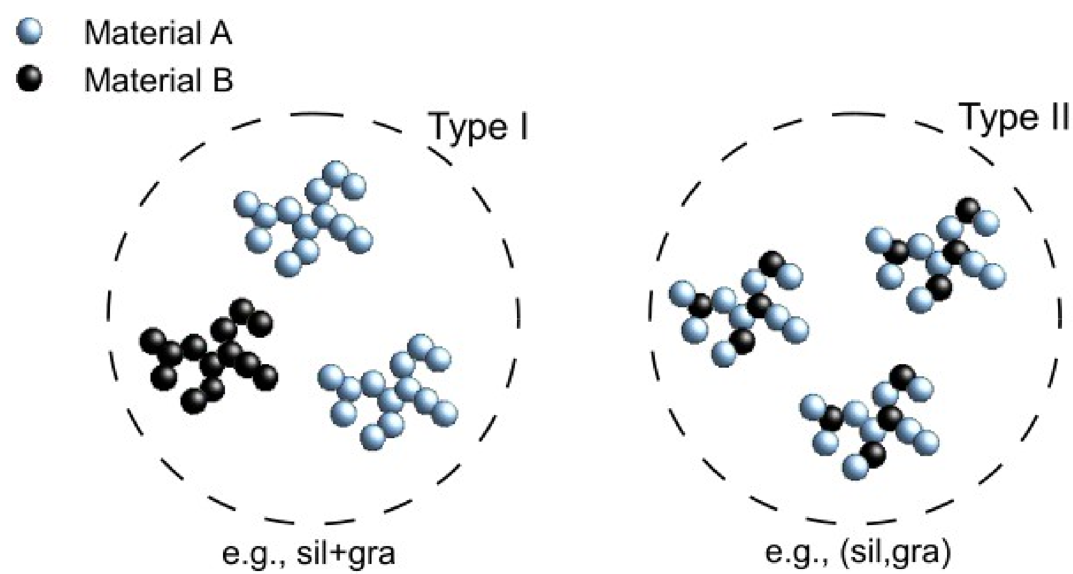
$$t_{coll,0} = \left(8.5 \times 10^4 \text{ yr} \left(\frac{a_0}{0.1\ \mu\text{m}}\right)^{1/2} \left(\frac{n}{10^5\ \text{cm}^{-3}}\right)^{-3/4} \left(\frac{T}{10\ \text{K}}\right)^{-1}\right.$$

Opacity calculations [Ormel+2011]

Effective medium theory

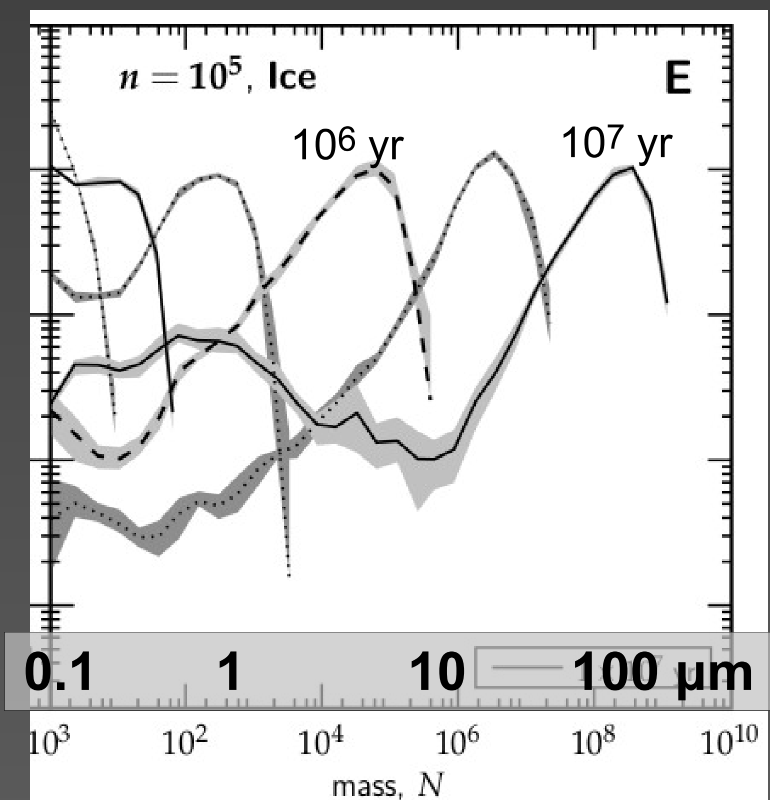
$$f_{\rm fill} \sum_{i=1}^{N_{\rm c}} f_i \alpha_{\rm c}(m_i/m_{\rm eff}) + (1 - f_{\rm fill})\alpha_{\rm c}(1/m_{\rm eff}) = 0,$$

- Bruggeman rule
- Previously good agreement with DDA simulations
  - Min et al. (2009)
- Includes porosity, silicate, & graphite

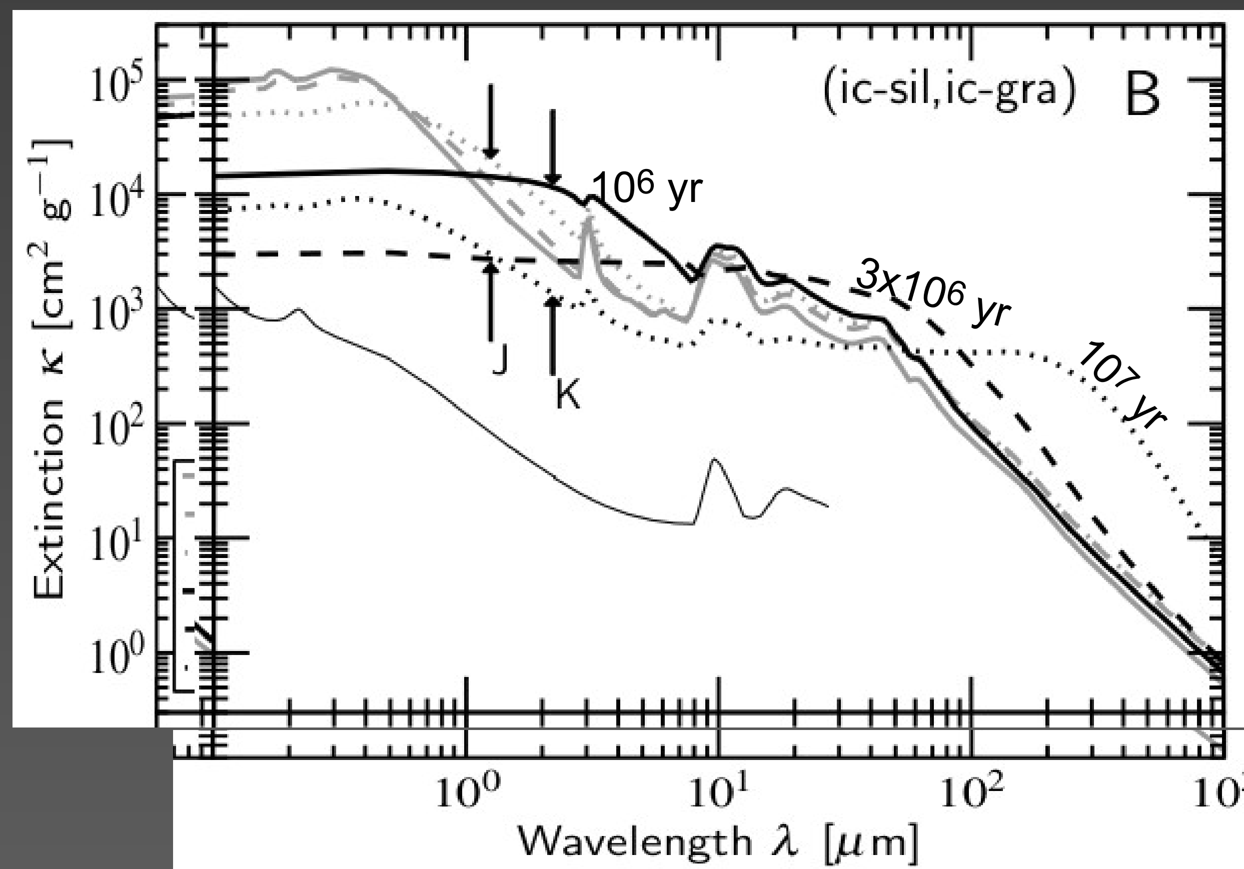


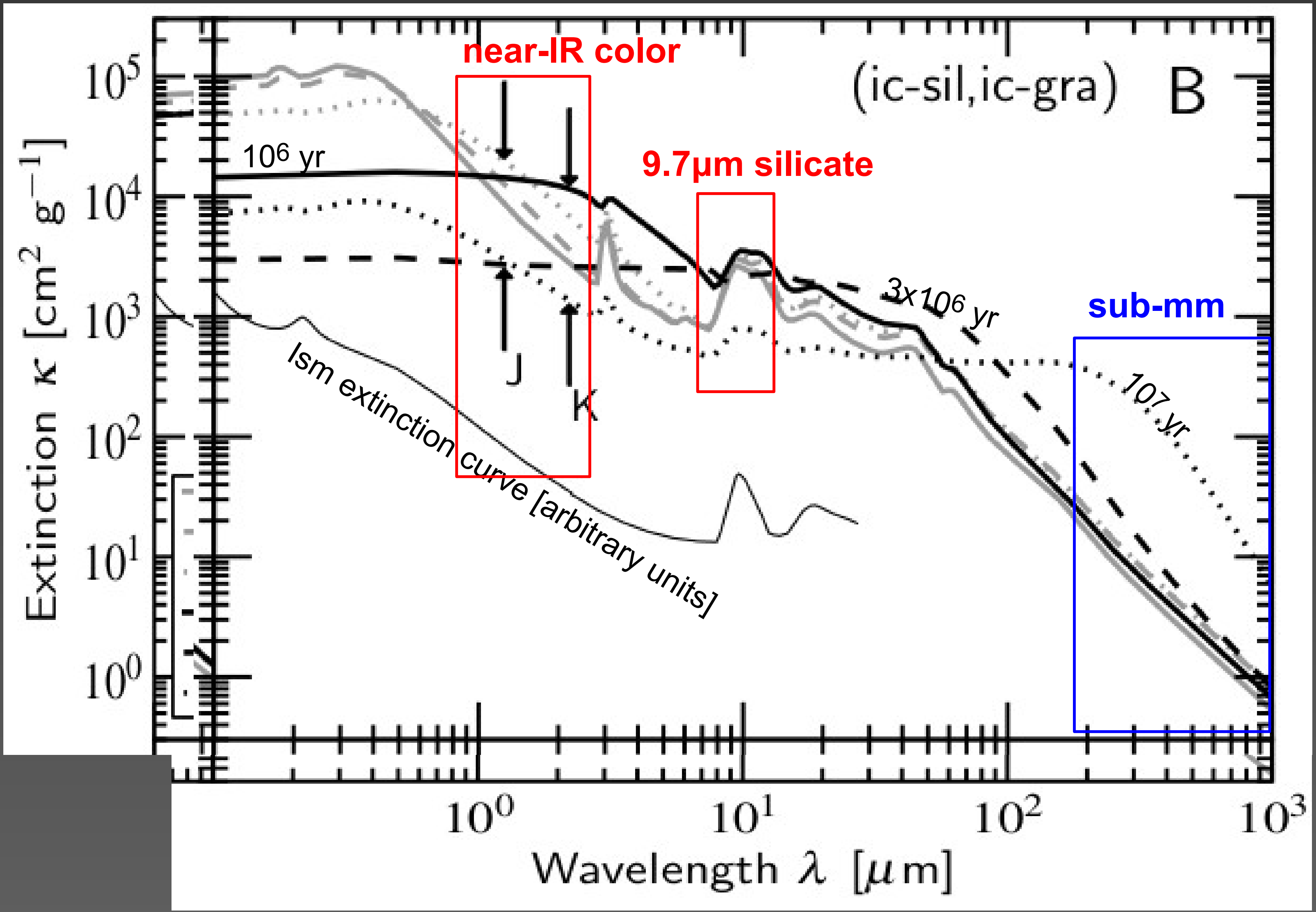
Extinction curve follows size distr.

Size distribution



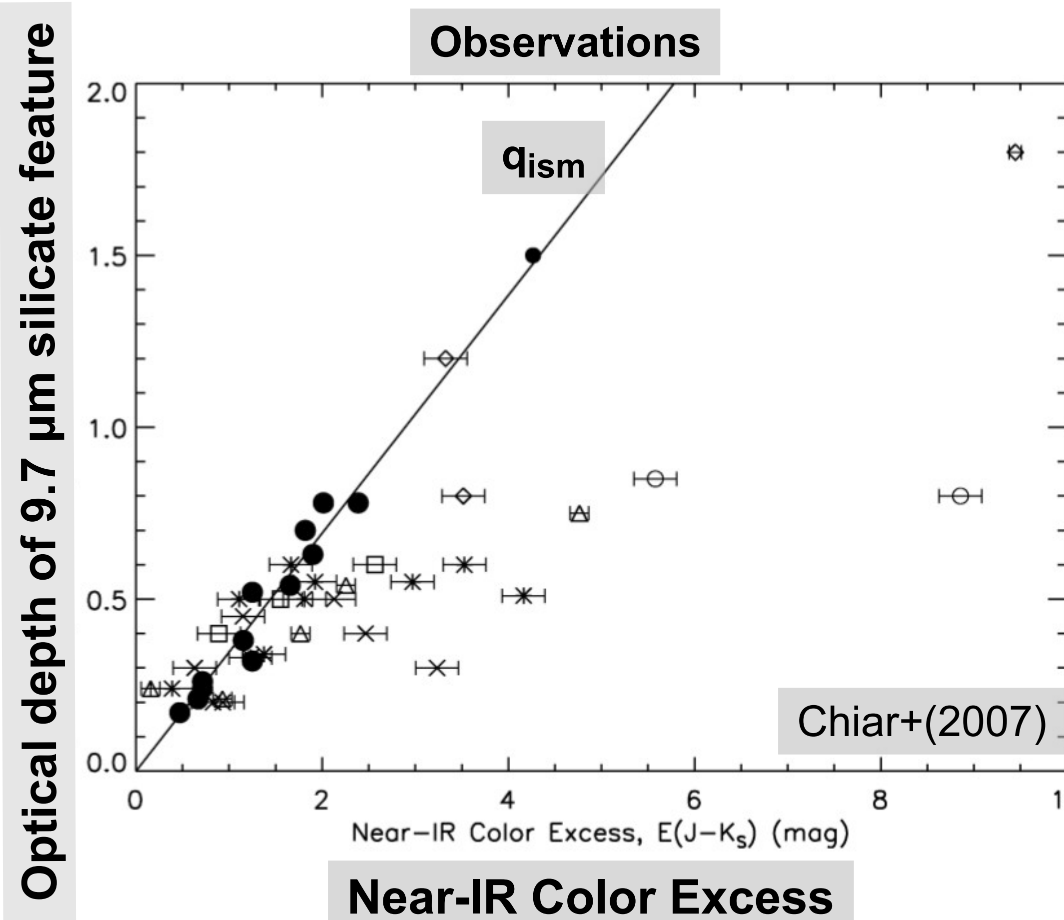
opacities

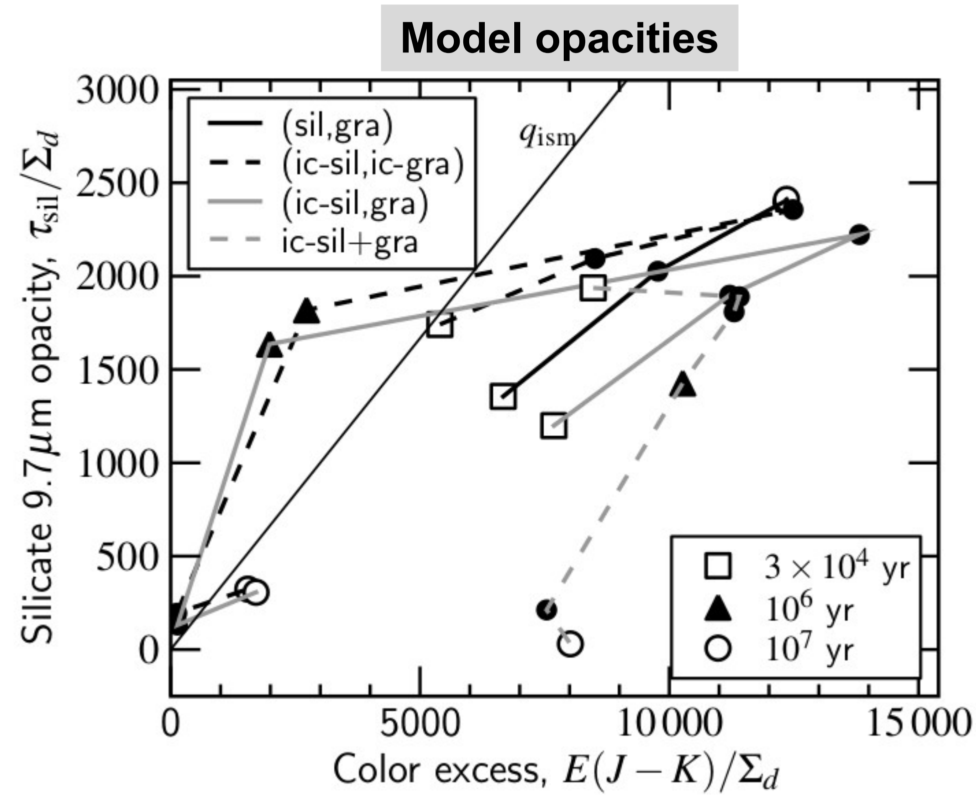




near-IR color
(ic-sil,ic-gra)
B
10⁶ yr
9.7μm silicate
J
K
3x10⁶ yr
sub-mm
10⁷ yr
Ism extinction curve [arbitrary units]
Extinction κ [cm² g⁻¹]
Wavelength λ [μm]

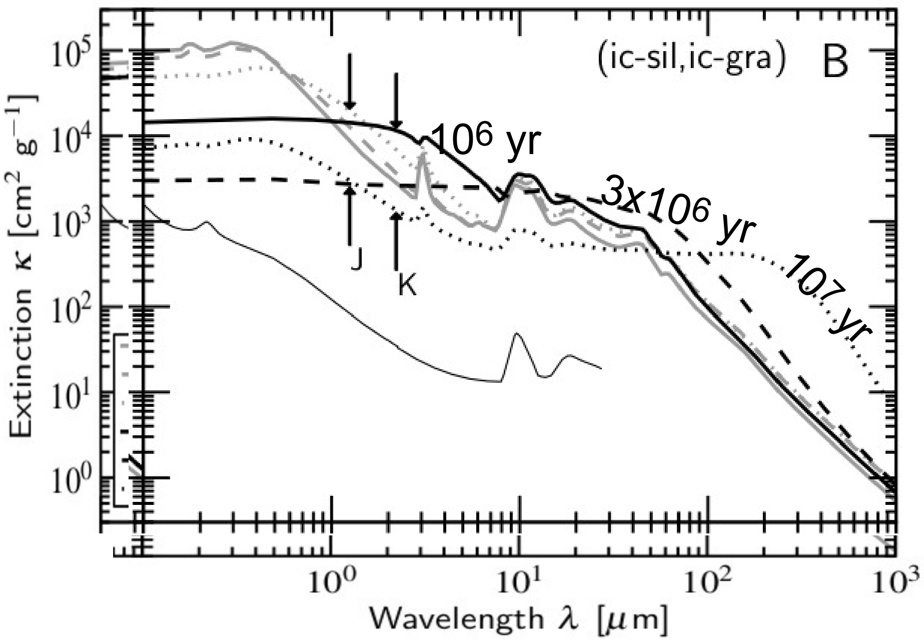
10μm vs near-IR colours





Observed relationship hard to explain with a (simple) coagulation scenario

Sub-mm indices β ($\kappa_\lambda \sim \lambda^{-\beta}$)



Time	$\kappa_{850} : \kappa_{2.2}$	β
10^5	3.0×10^{-4}	2.0
10^6	7.9×10^{-5}	2.0
3×10^6	4.6×10^{-4}	2.3
10^7	7.2×10^{-3}	3.3

β=κ(850μm):κ(500 μm)

Find β>2 (see Planck Collaboration results)
Alternative explanation: temperature effect
[eg. Mennella+1998, Boudet+2005, Demyk poster]

Multi-wavelength observations required to discern scenario
[cf. Shirley+2011]

Conclusions/Takaways

Cores MC laboratory dust aggregation process

Ice mantles facilitate coagulation

Potential growth $t_{coll,0}$ vs t_{life}

- When $t_{life} \sim t_{ff}$ growth is limited

Opacities

- Mixing/ice mantle formation influences $\kappa(\lambda)$
- Multi-wavelength *modeling* to constrain