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Restructuring of colloidal aggregates in turbulence

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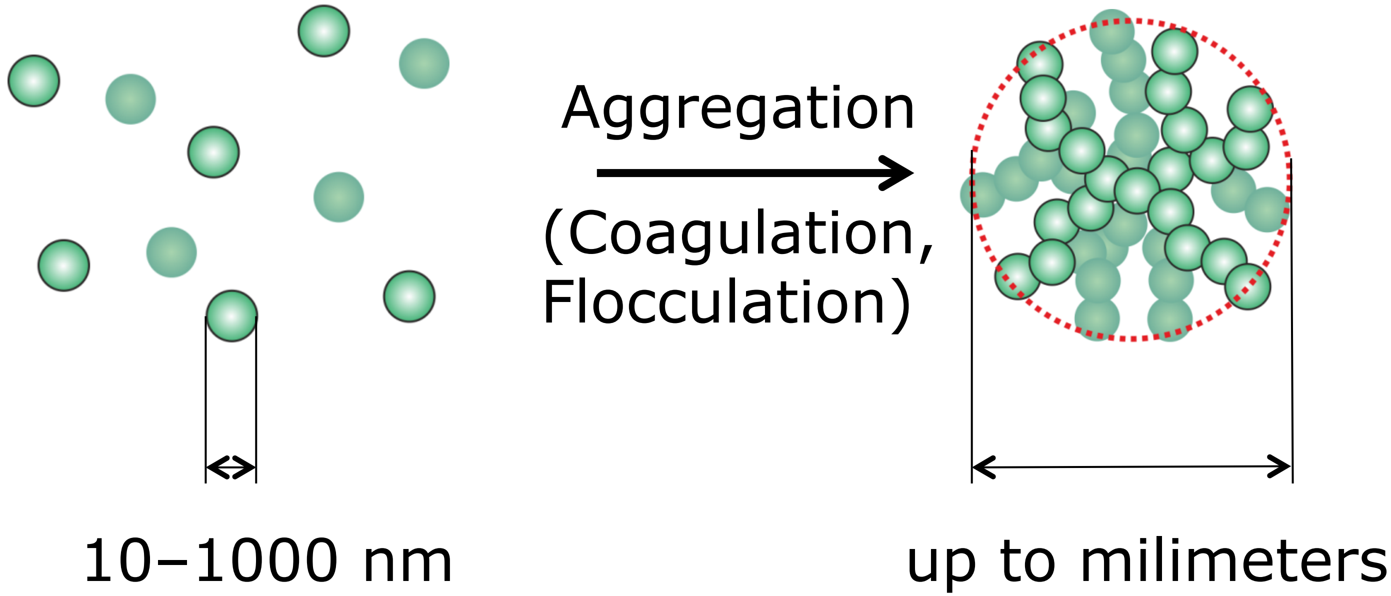
Colloids and colloidal aggregation



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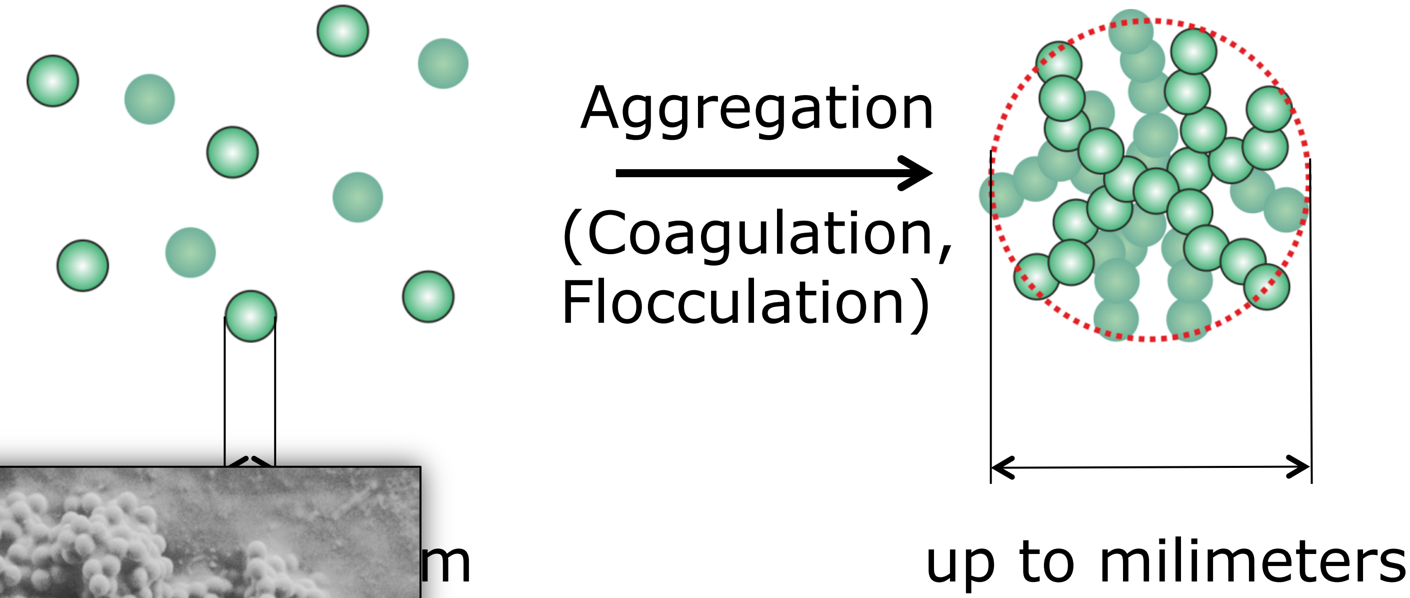
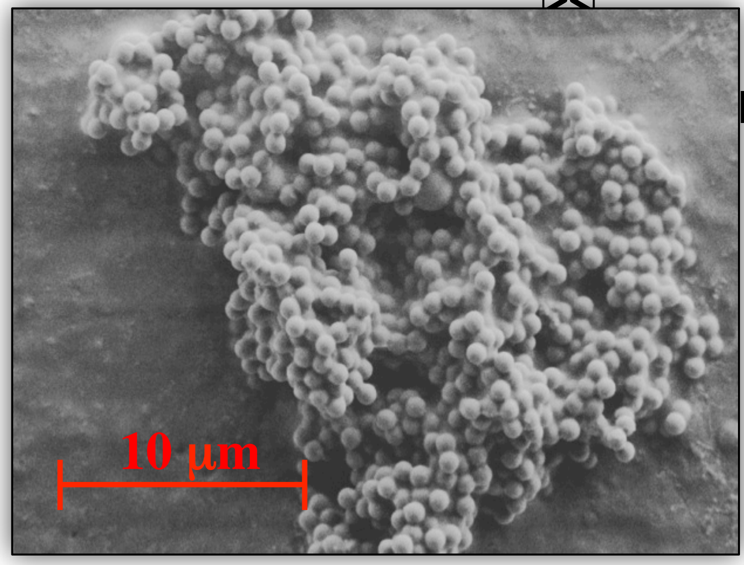
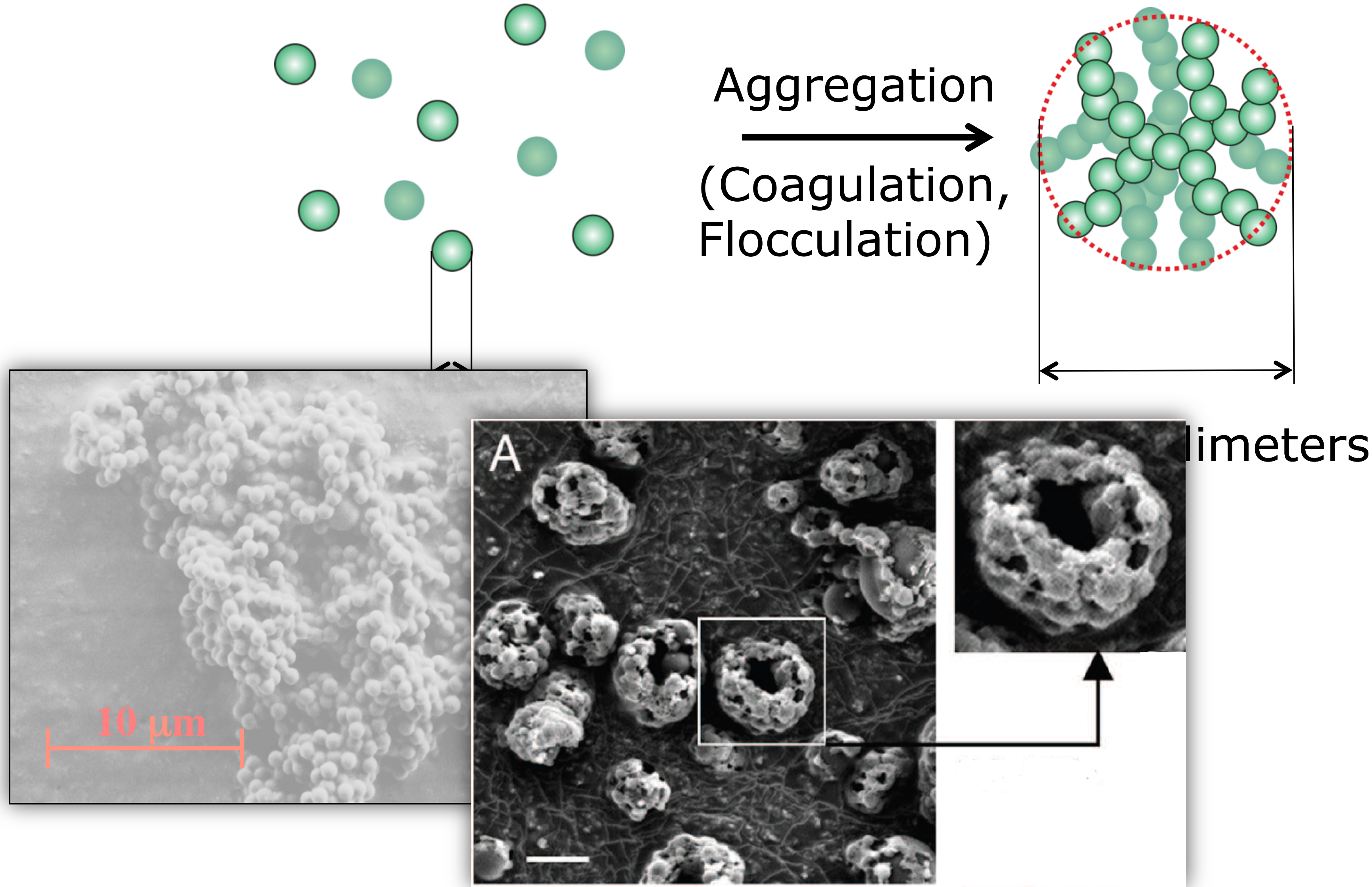




Picture: Soos et al., J. Colloid Interface Sci. (2008)

Colloids and colloidal aggregation



Picture: Korin et al., *Science* (2012)

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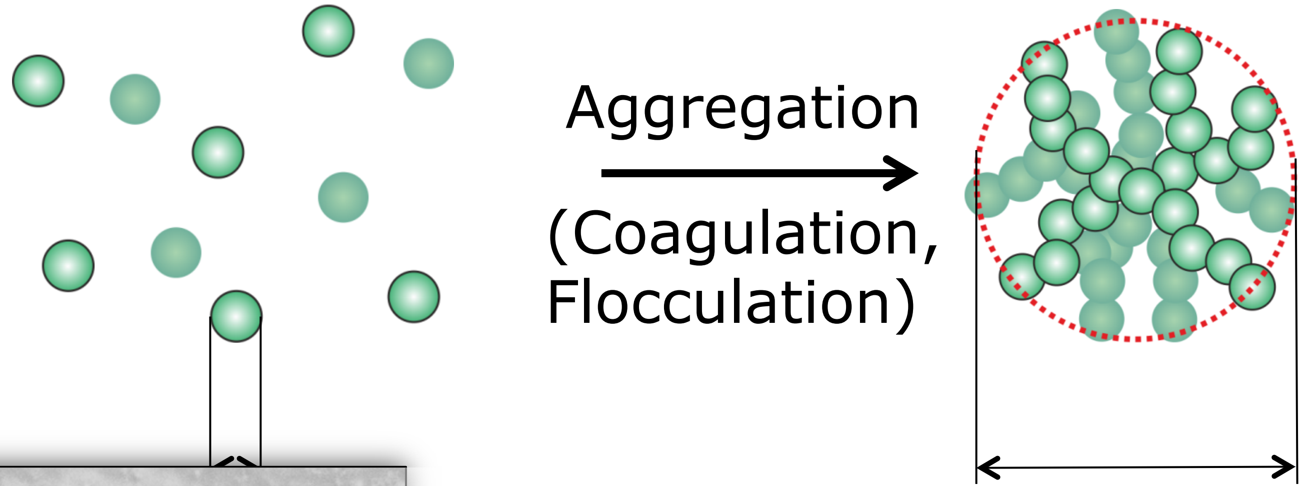
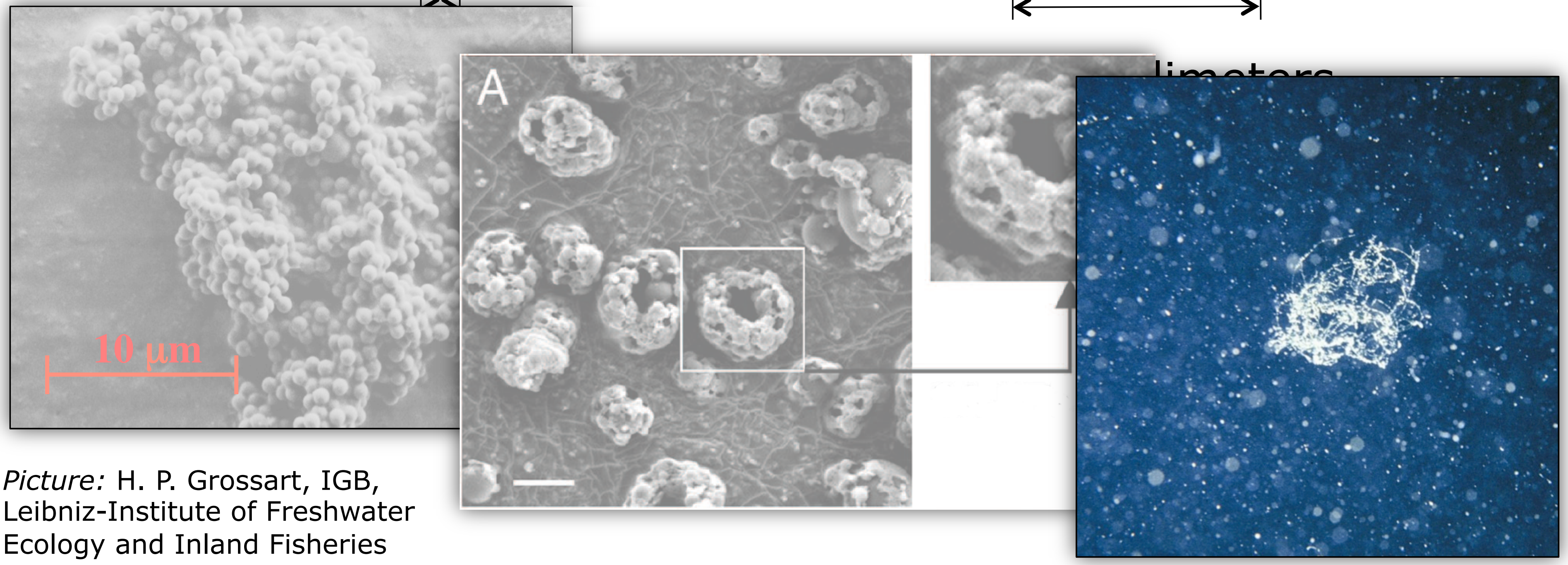
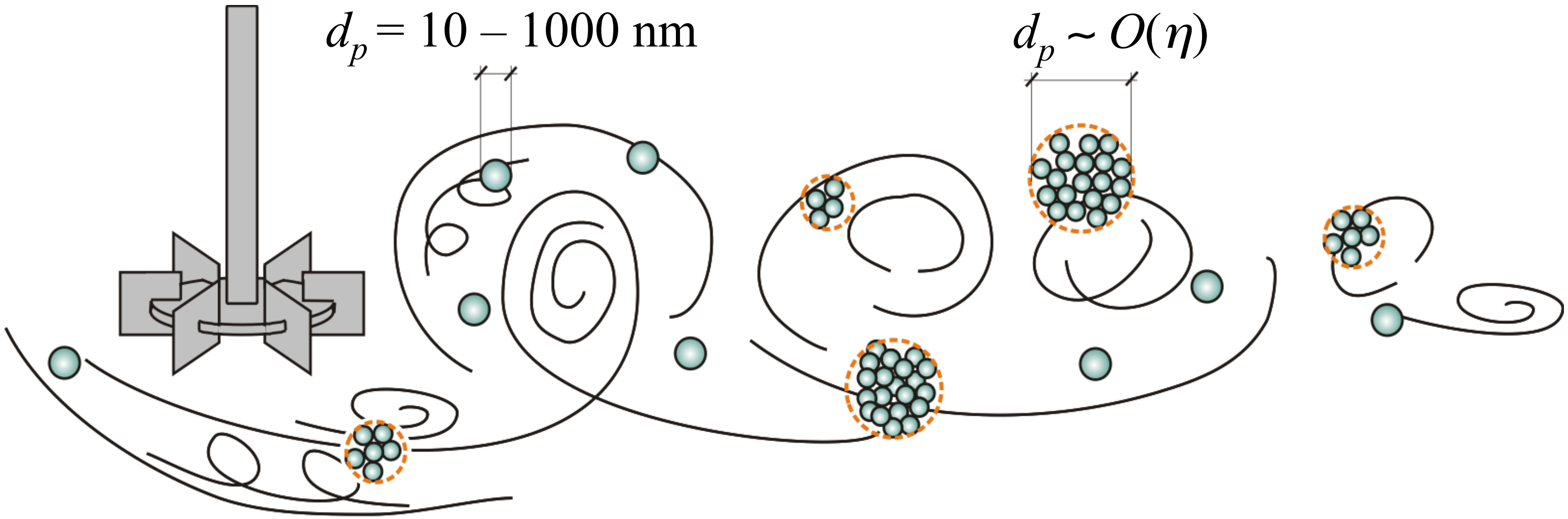




Picture: H. P. Grossart, IGB, Leibniz-Institute of Freshwater Ecology and Inland Fisheries

Colloids and colloidal aggregation



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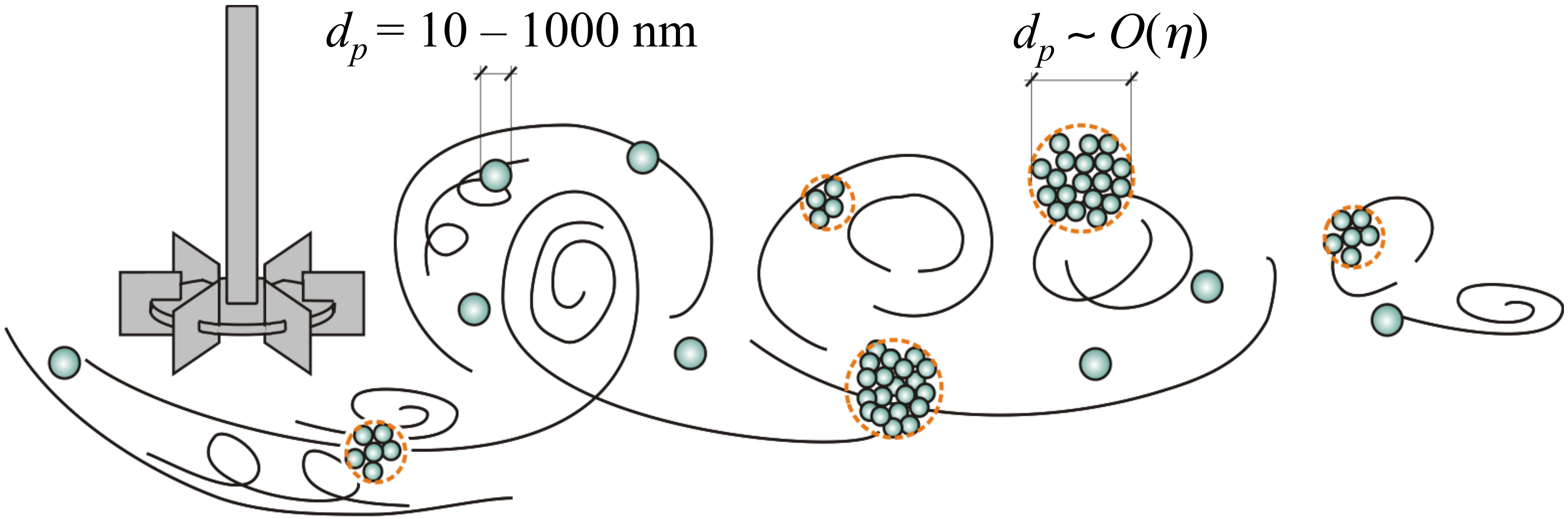
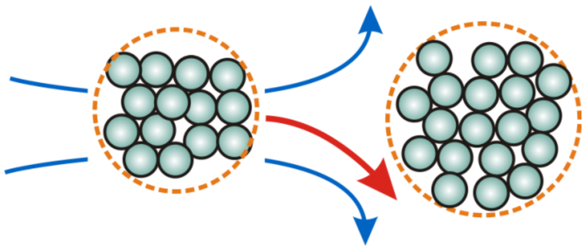
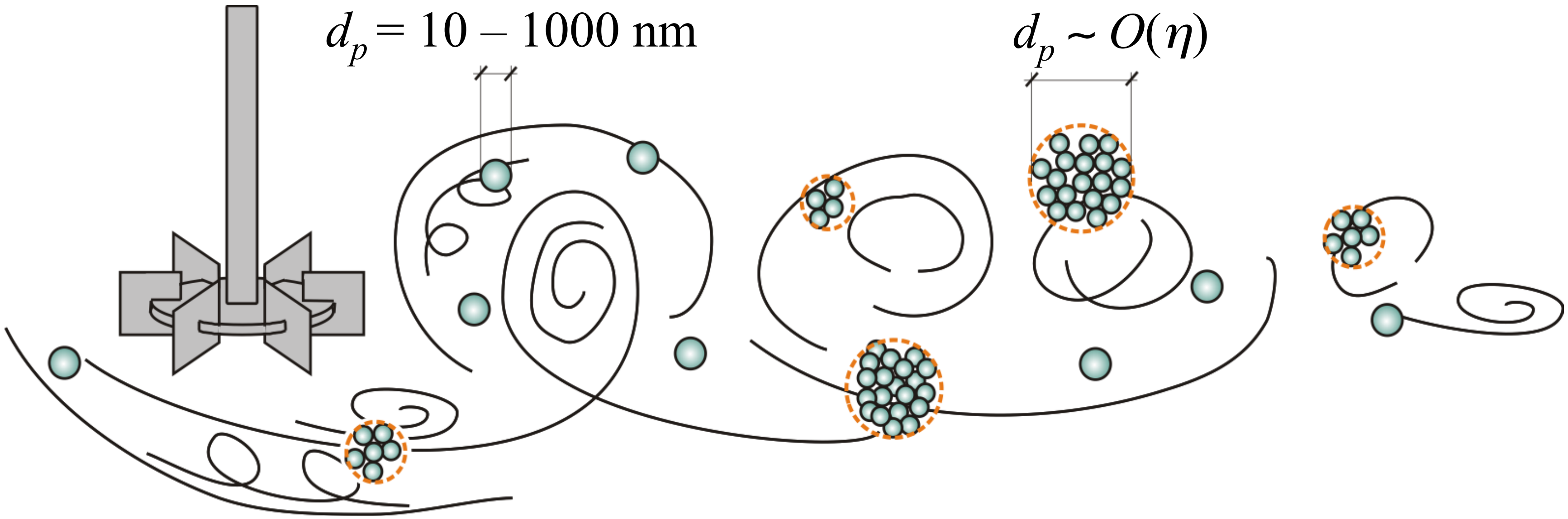
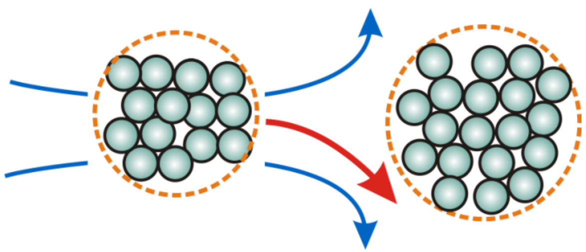




Flow induced aggregation

Colloids and colloidal aggregation

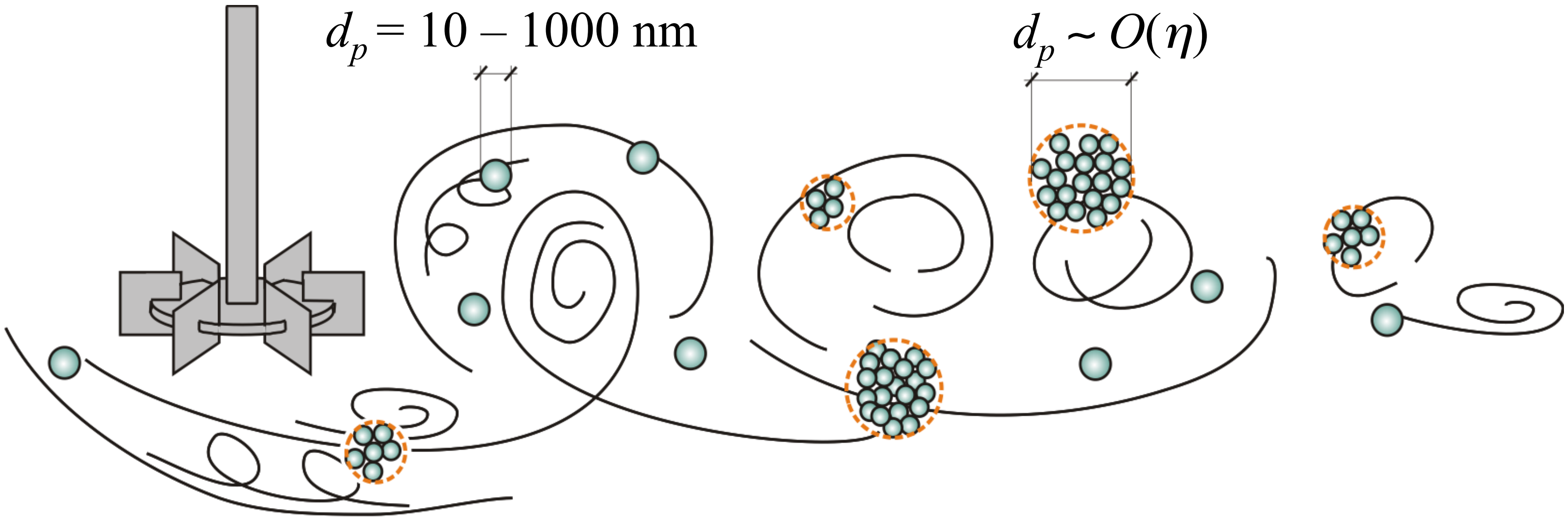


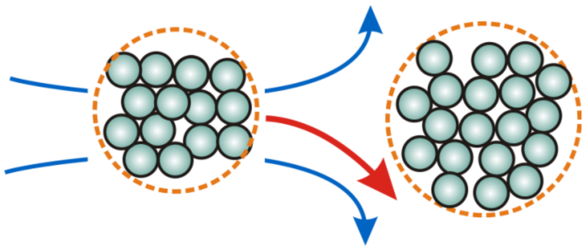


Flow induced aggregation

Breakup

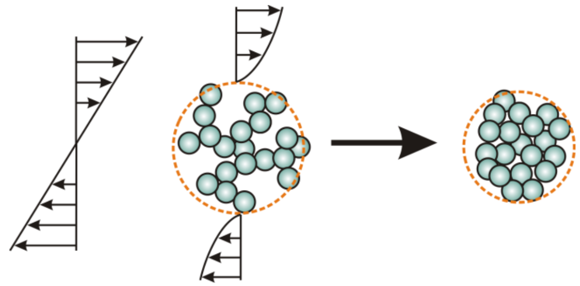
Colloids and colloidal aggregation





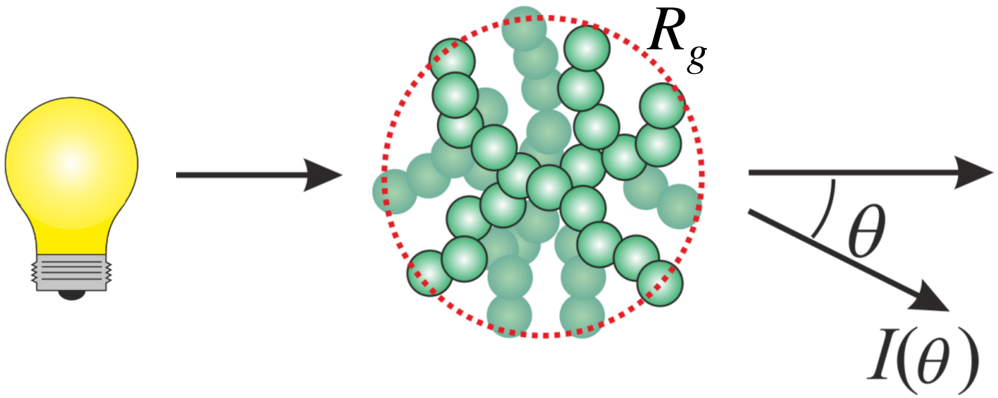
Flow induced aggregation

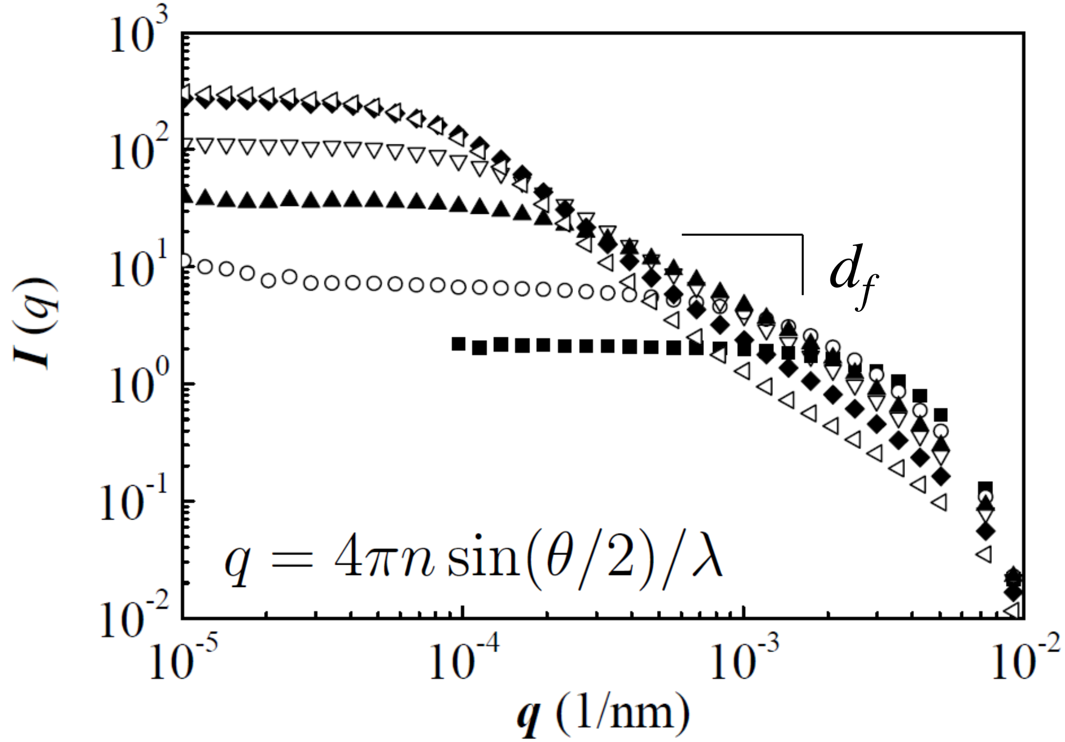
Breakup



Restructuring

Structure of colloidal aggregates



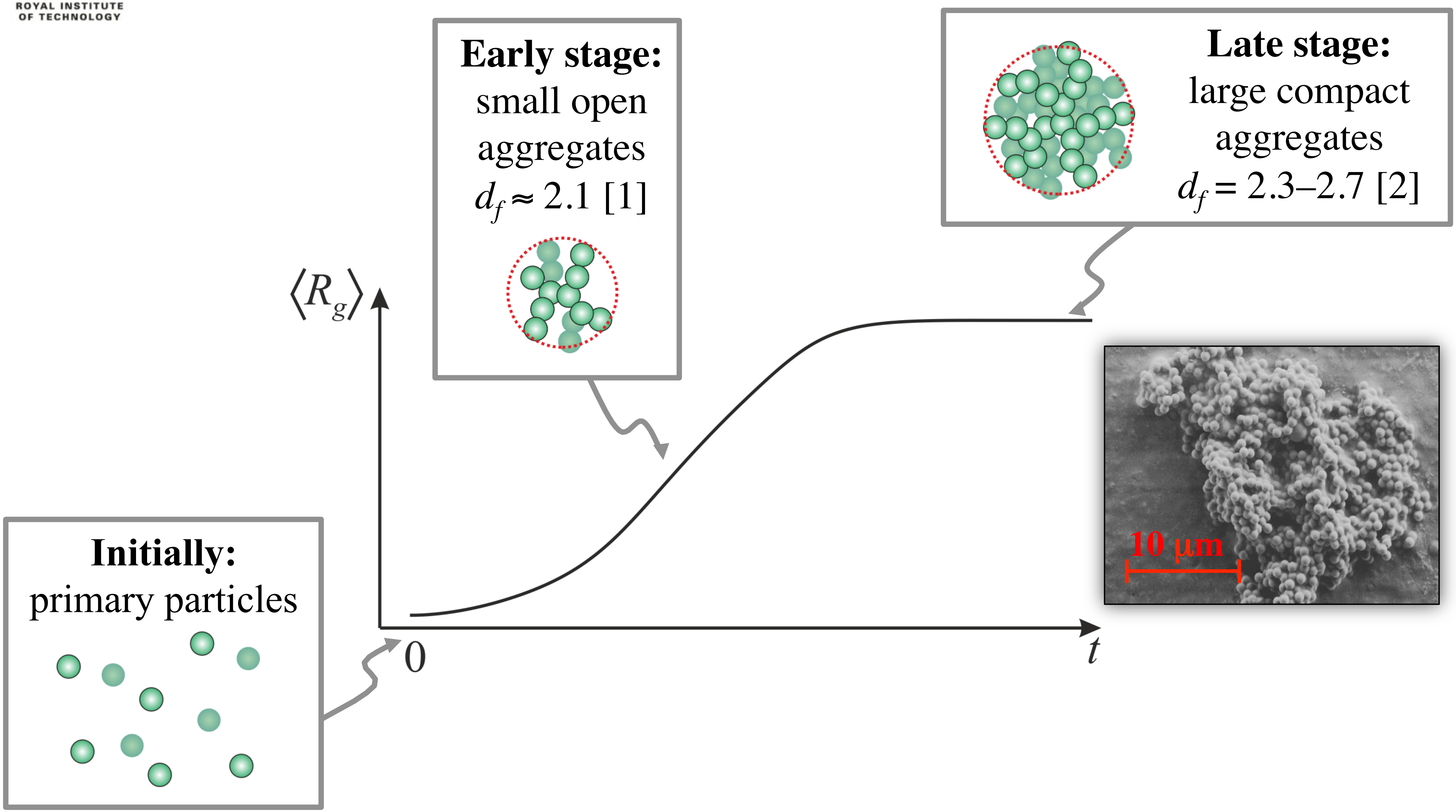


$$i \sim R_g^{d_f}$$

For $d_p \ll \lambda$: d_f from the log-log slope

Moussa *et al.*, *Langmuir* (2007)

Restructuring of aggregates



[1] Babler *et al.*, *Langmuir* (2010), [2] Soos *et al.*, *J. Colloid Interface Sci.* (2008), Ehrl *et al.*, *Langmuir* (2008)

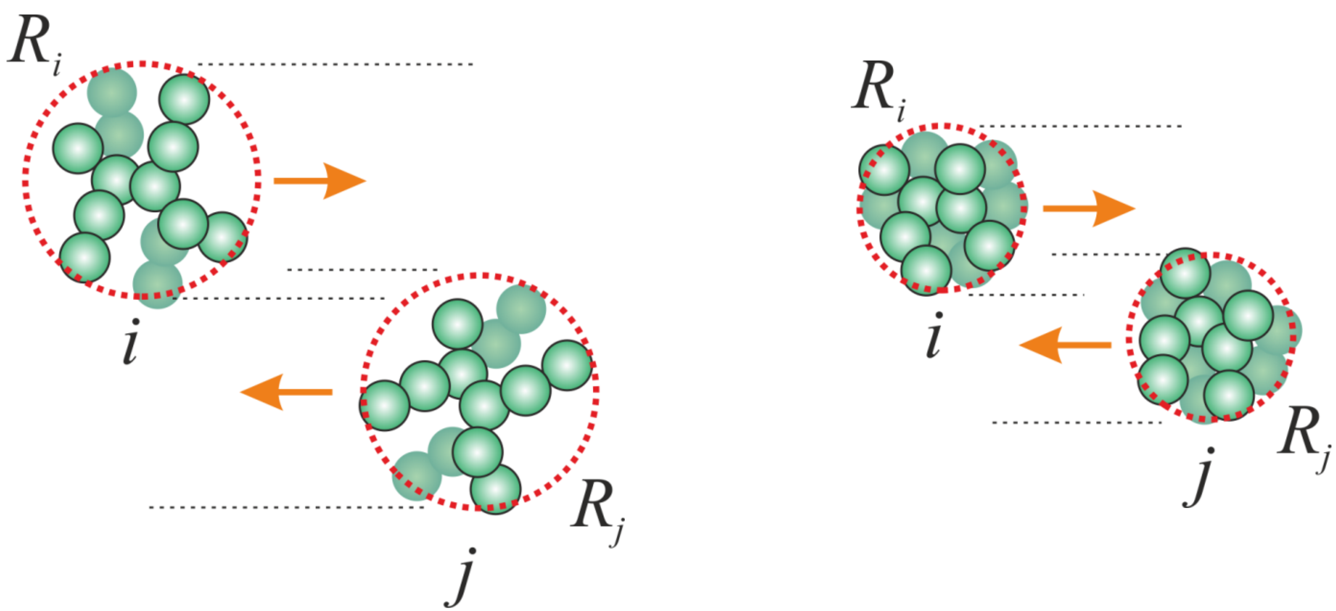
Aggregation kinetics in flows

Consider an aggregate i colliding with an aggregate j

i, j = number of primary particle per aggregate

Open aggregate
Small d_f

Dense aggregates
large d_f



$$K_{ij} \sim \left(R_i + R_j\right)^3 \sim \left(i^{1/d_f} + j^{1/d_f}\right)^3$$

⇨ d_f can be estimated from measuring the aggregation rate

Aggregation kinetcs: Population balance equations

- Homogeneous suspension
- Aggregation, breakup, and restructuring
- Evolving fractal dimension
  - At a given time, all aggregates have the same d_f

$$\frac{dN_i}{dt} = \frac{1}{2}\sum_{j=1}^{i-1} \overset{d_f(t)}{K_{A,j,i-j}} N_j N_{i-j} - N_i \sum_{j=1}^{\infty} K_{A,i,j} N_j$$

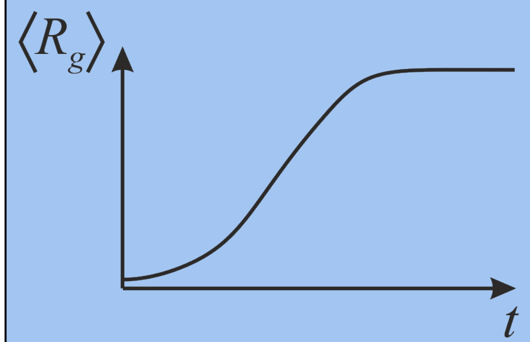
$$- K_{B,i} N_i + \sum_{j=i+1}^{\infty} g_{i,j} K_{B,j} N_j$$

- $K_{A,\mathrm{i,j}}$: Porous sphere model [1]
  - Takes into account hydrodynamic and colloidal interaction
- $K_{B,i}$: Critical stress model [3]

[1] Babler, AIChE J. (2008), Babler et al., Langmuir (2010), [2] Babler et al. J. Fluid Mech. (2008), Babler et al. PRE (2012)

Plan

Measure experimentally the evolution of the CMD $N_i(t)$ [respectively moments of it]



→

Fit the measured evolution of the moments of $N_i(t)$ by PBE, allowing for a evolving fractal dimension

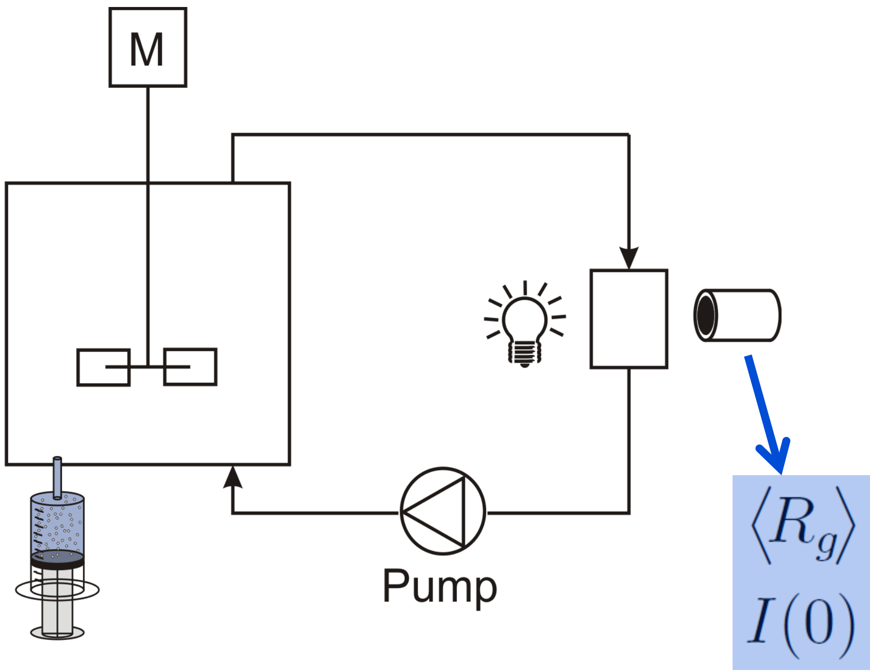
→

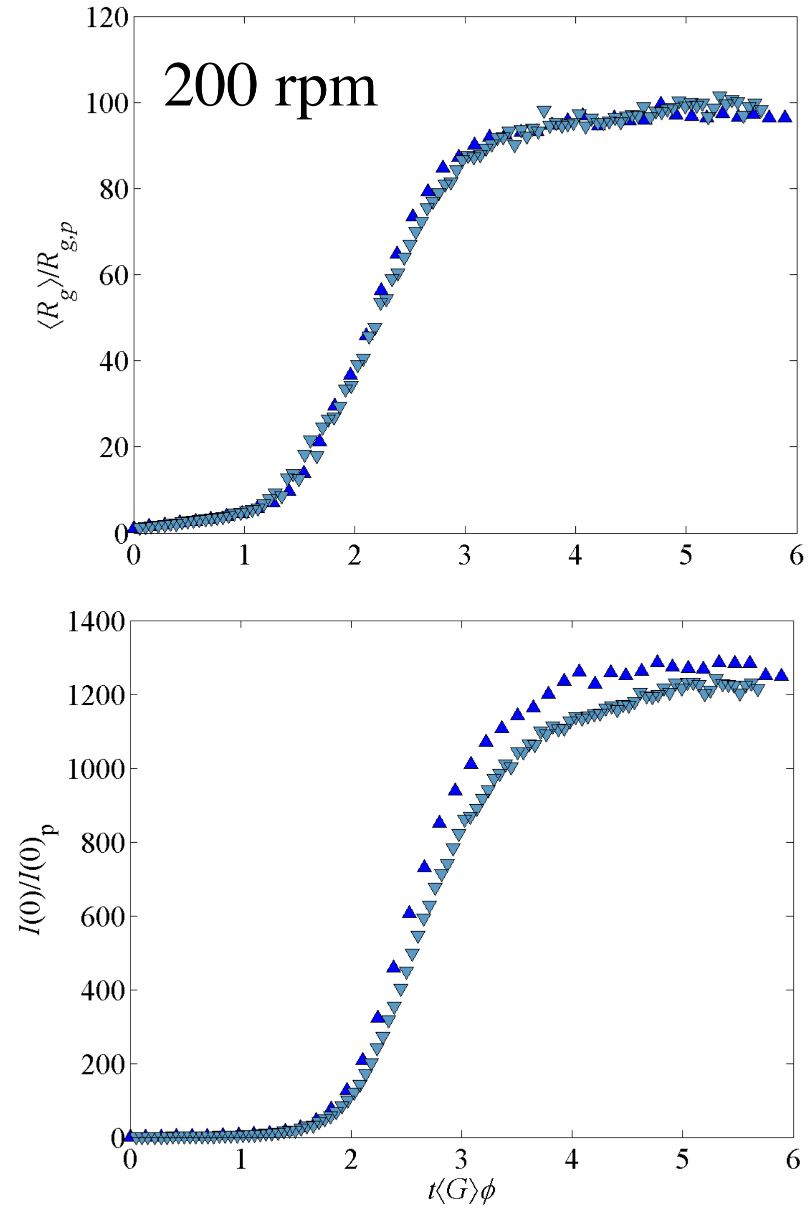
Dynamics of restructing $d_f(t)$

↑

- Breakage parameter from the behavior of the steady state at different rpm
- Symmetric binary breakage

Experimental

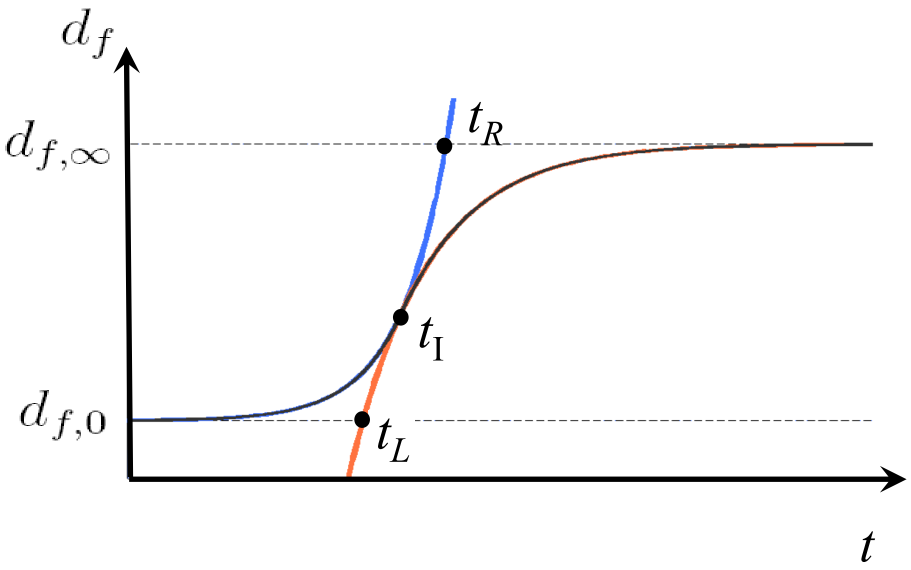




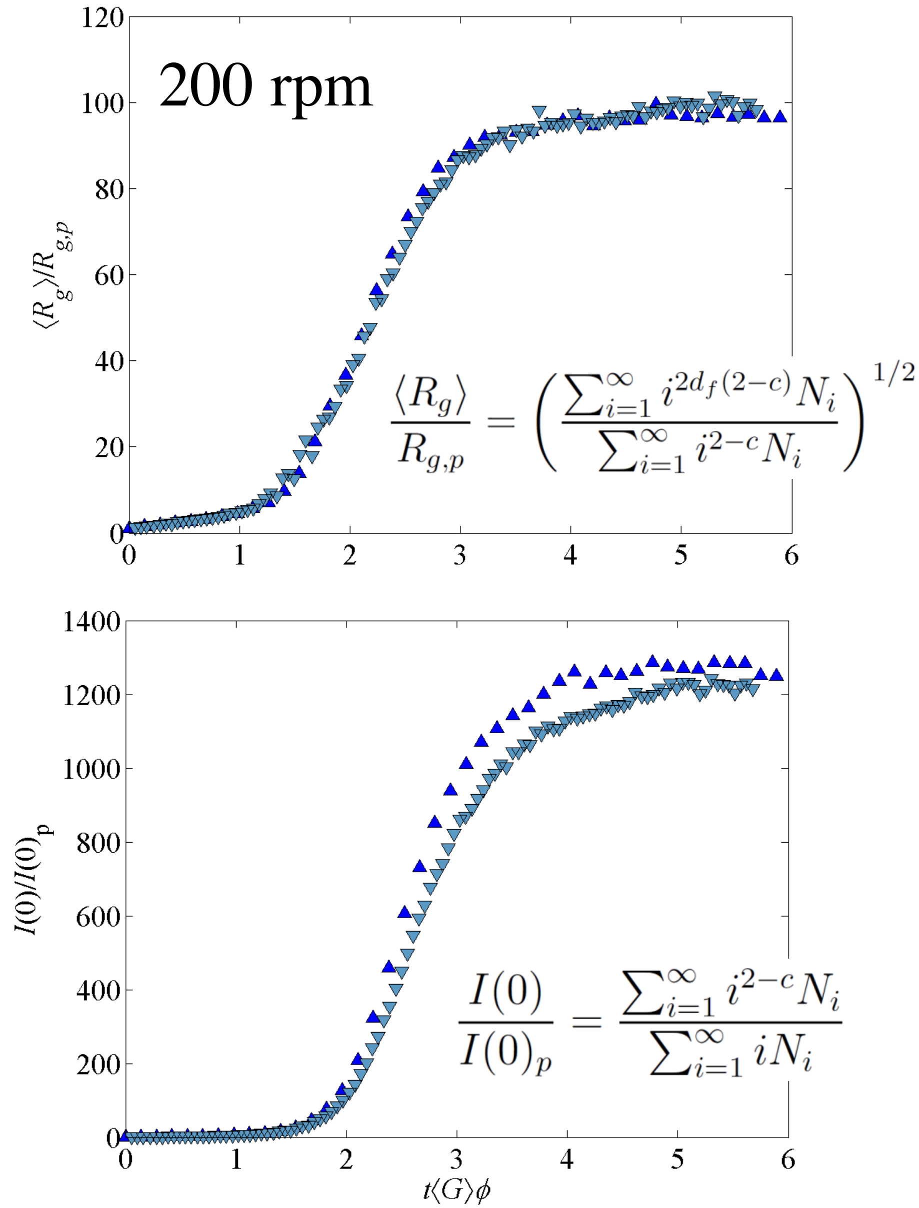
- Polystyrene particles
- $d_p = 420$ nm, $\phi = 2 \times 10^{-5}$
- Coagulant: $Al(NO_3)_3$, 0.16 w%
- Fully destabilized particles

Experimental

- PBE to solve for $N_i(t)$
- Parameterized function for $d_f(t)$ to describe the evolution of the aggregate structure



- $d_{f,0} = 2.10$ from initial growth
- $d_{f,\infty} = 2.34$ from regrowth experiments



Results

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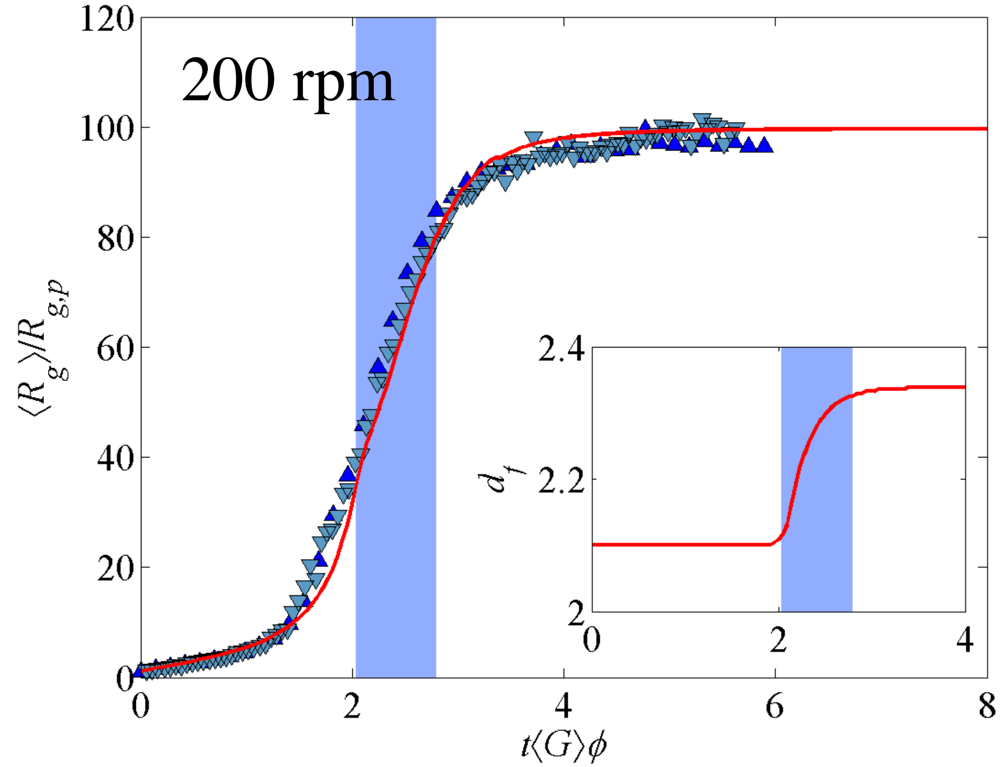
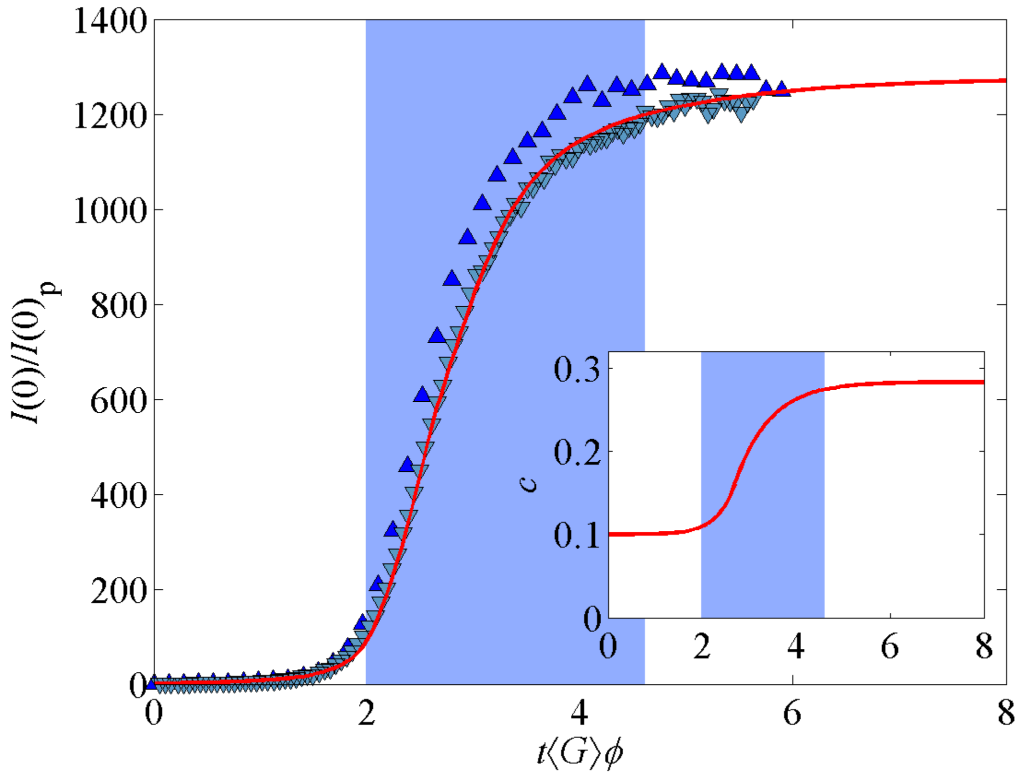
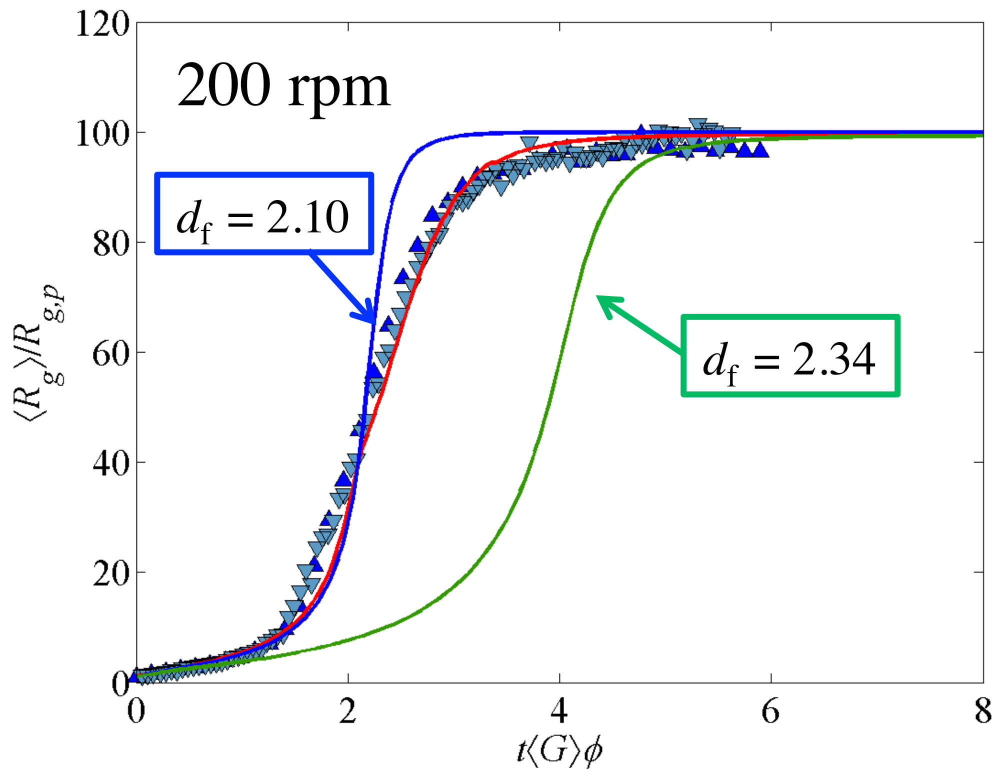
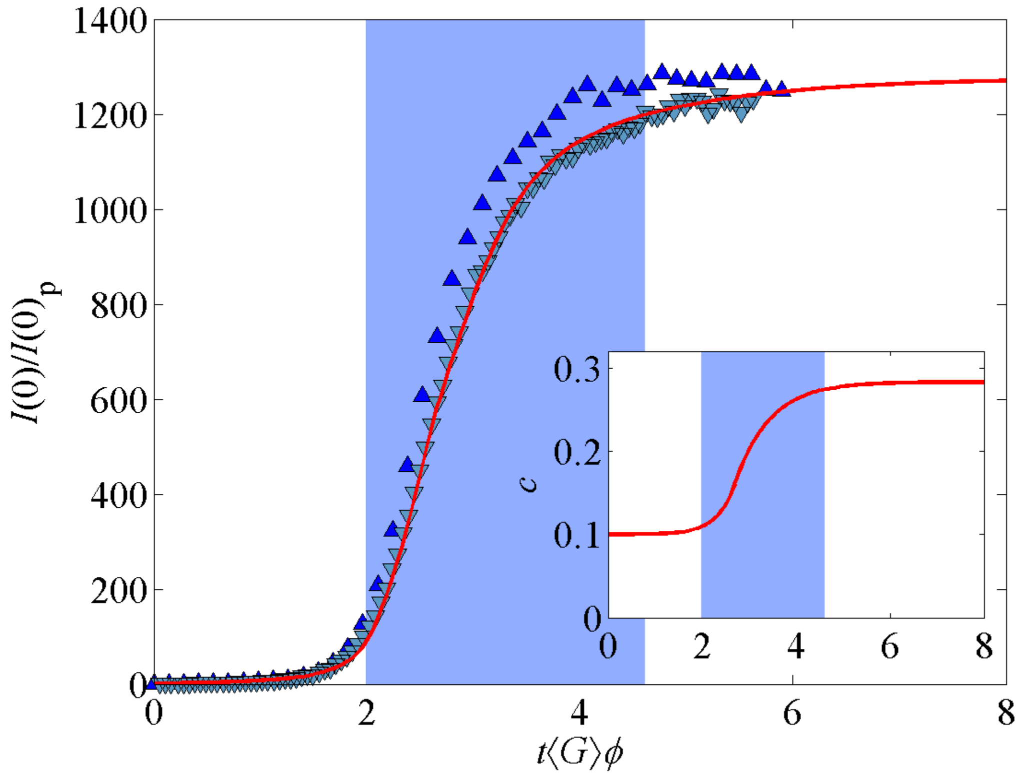




Fitting $d_f(t)$ and $c(t)$ to the evolution of $\langle R_g \rangle$ and $I(0)$

Results





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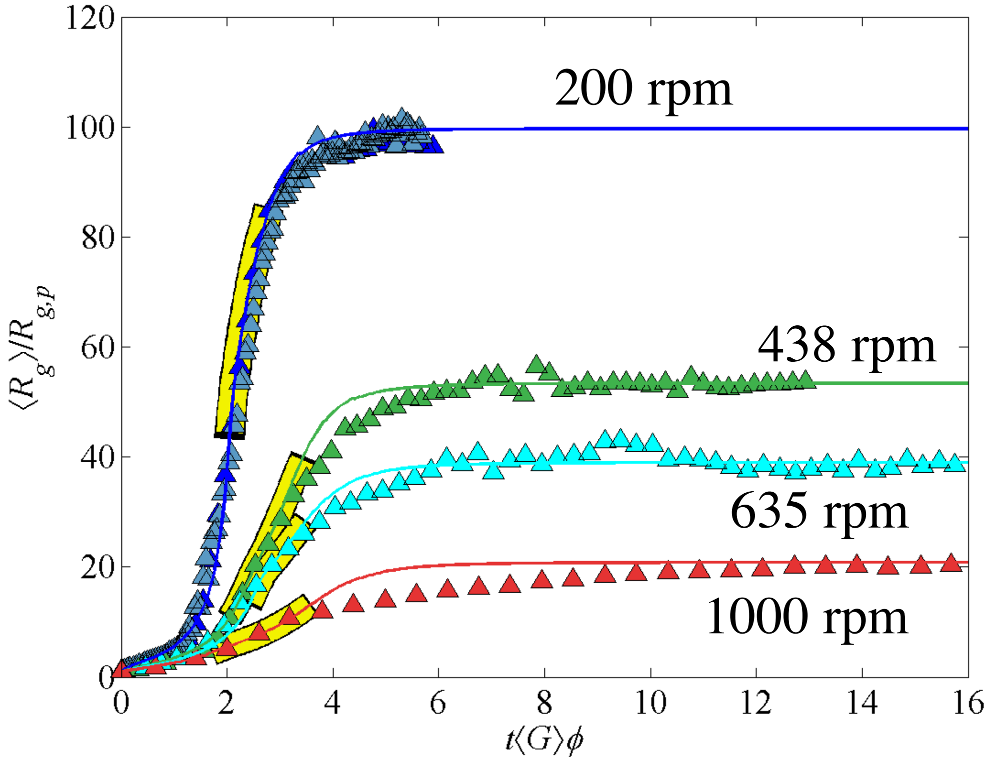
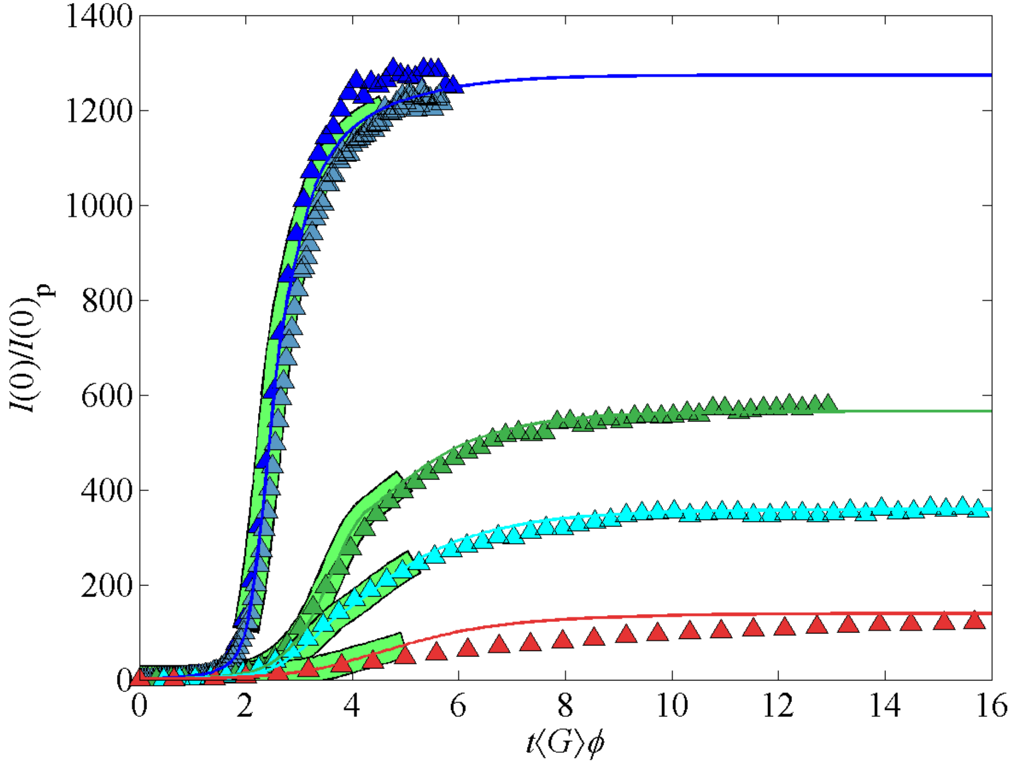
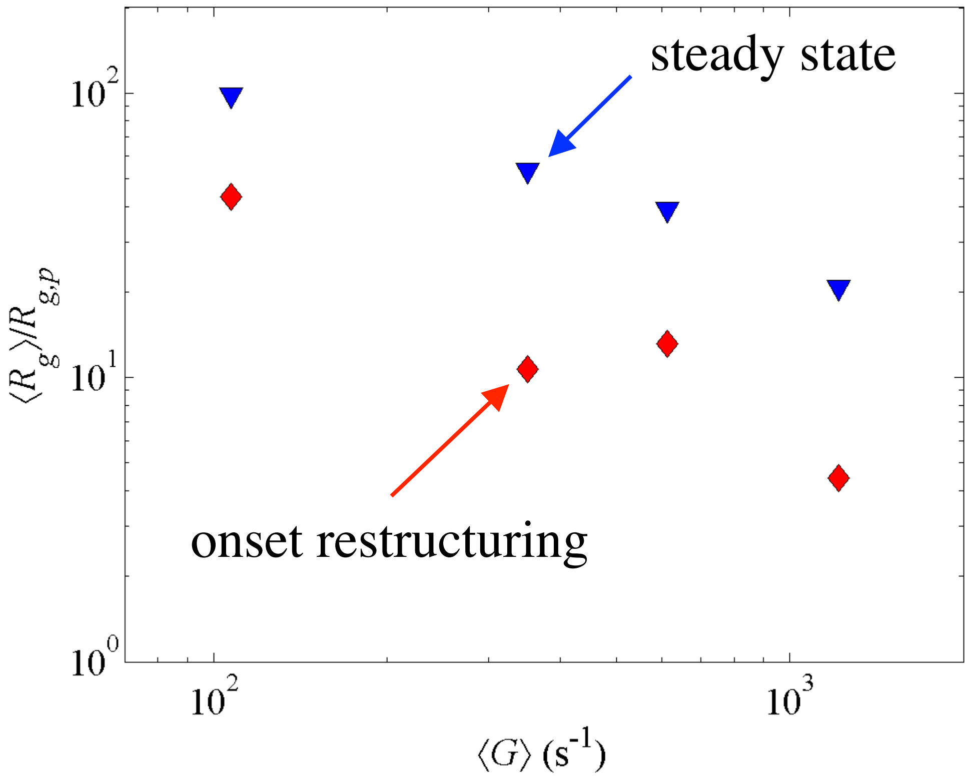
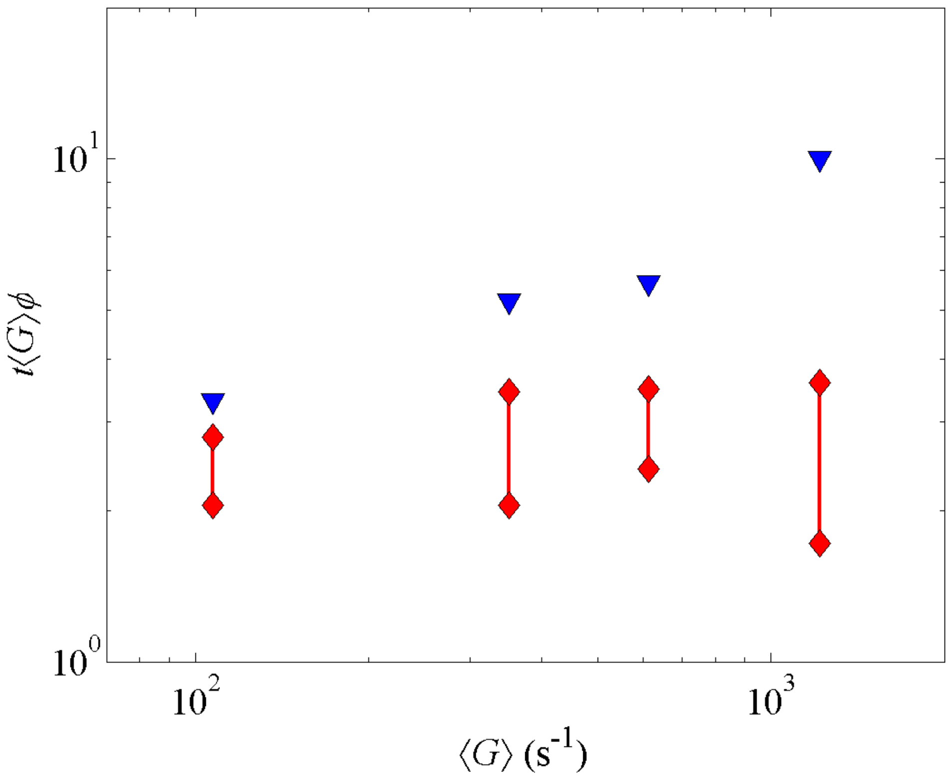




Fitting $d_f(t)$ and $c(t)$ to the evolution of $\langle R_g \rangle$ and $I(0)$

Onset and duration of restructuring





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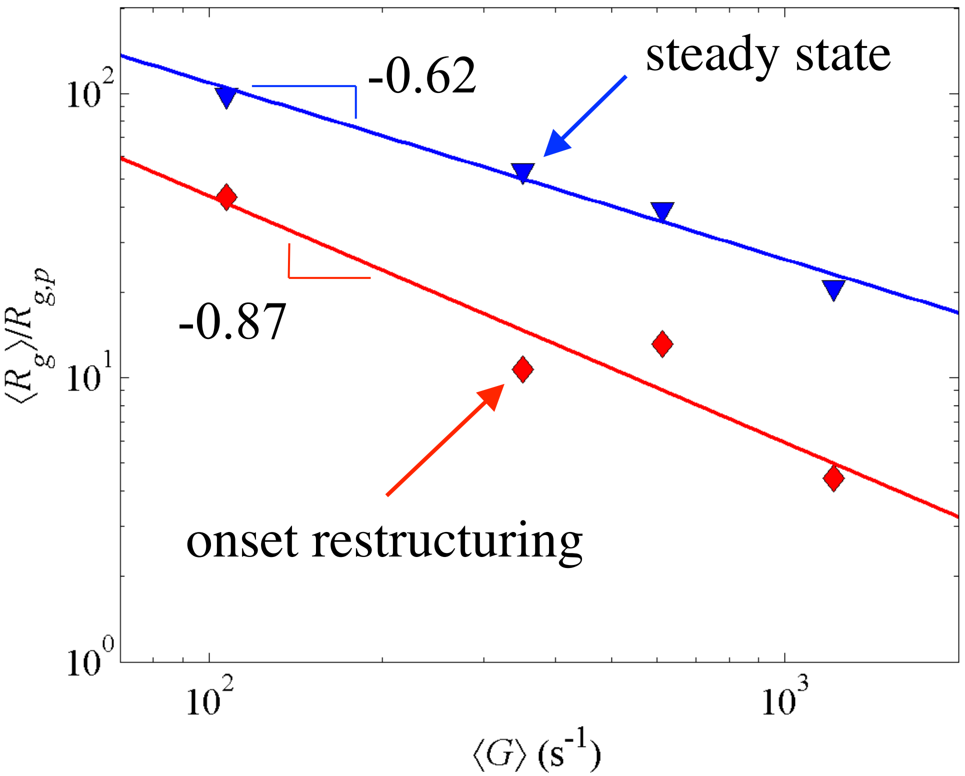
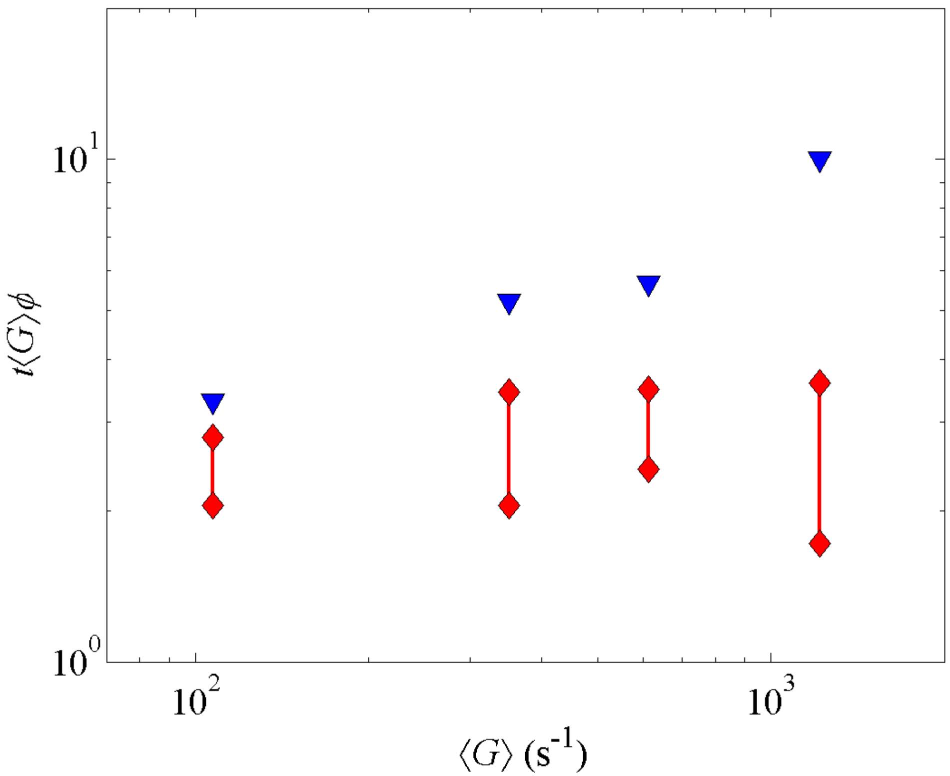
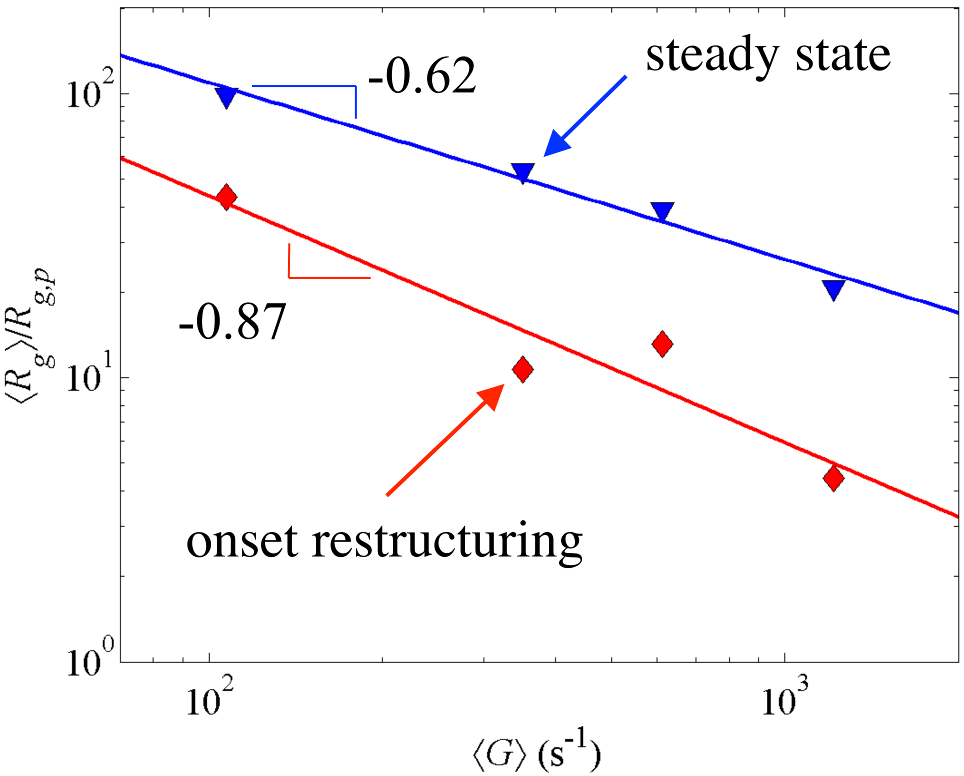
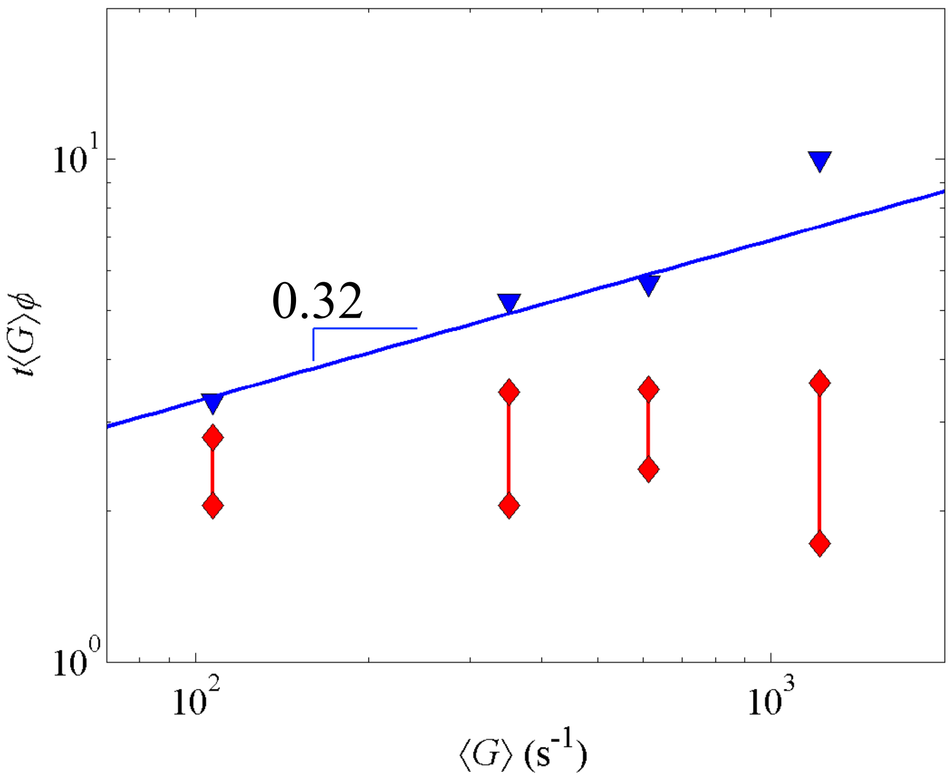




- The onset of restucturing is more sensitive to the shear rate G

Onset and duration of restructuring





- The onset of restucturing is more sensitive to the shear rate G
- The duration of restructuring scales with the shear rate G

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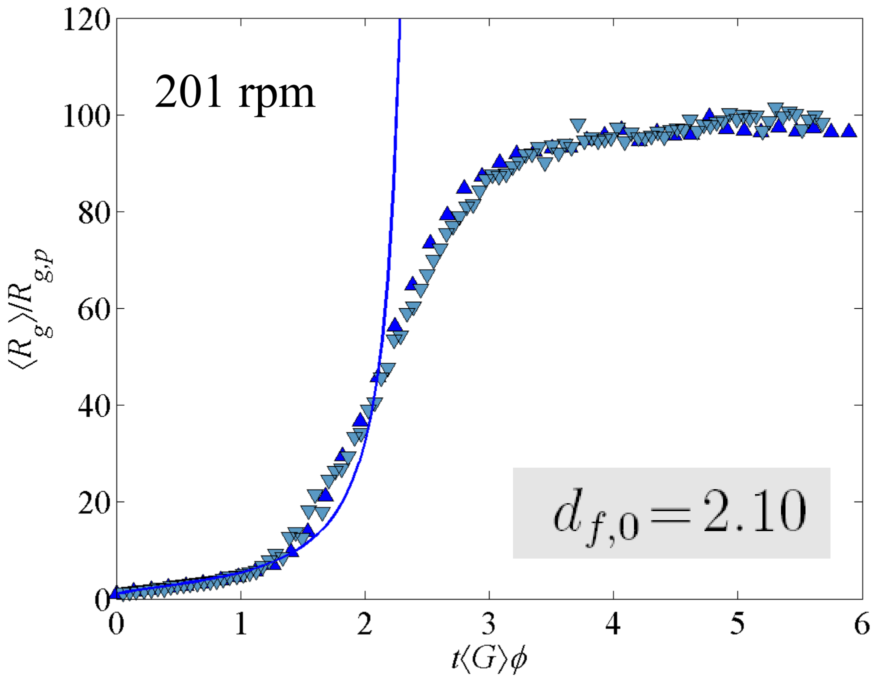
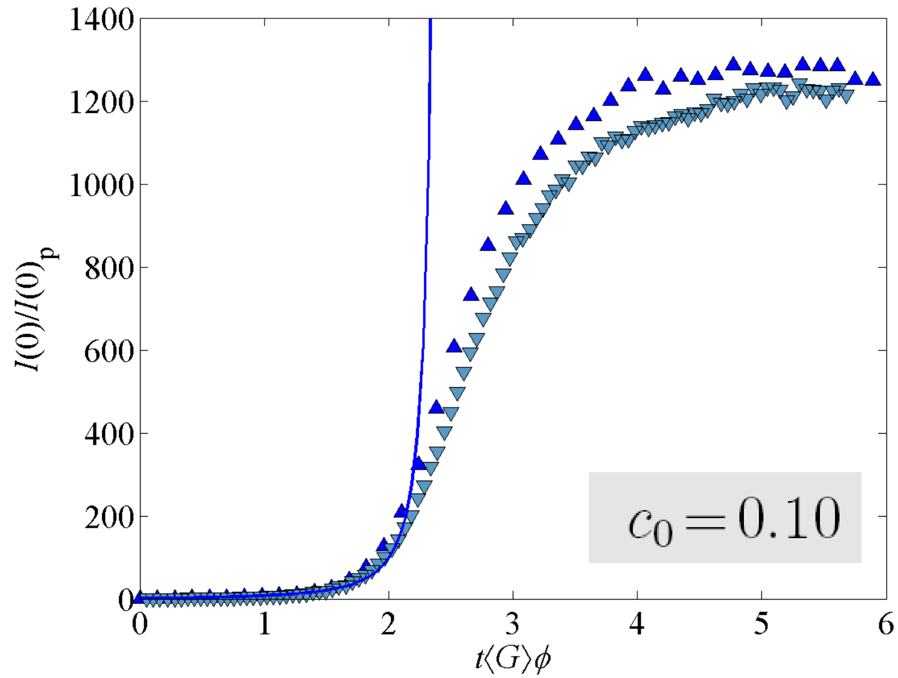
Conclusions

- Restructuring, in terms of the evolution of the fractal dimension, has been explored by fitting a PBE model to a set of experimental data.
- Restructuring sets in as the aggregates reach a certain size, and it is finished before they reach the steady state size.
- The aggregate size for the onset of restructuring depends stronger on the shear rate than the steady state aggregate size. This contradicts findings of Vanni and Gastaldi, *Langmuir* (2011) who studied open isostatic clusters by DEM.
- Restructuring is relatively fast and is duration scales approximately with the shear rate.
- Macromixing becomes important at high stirring speeds.

Initial fractal dimension

Initial Aggregate Growth → PBE Model w/o Breakage

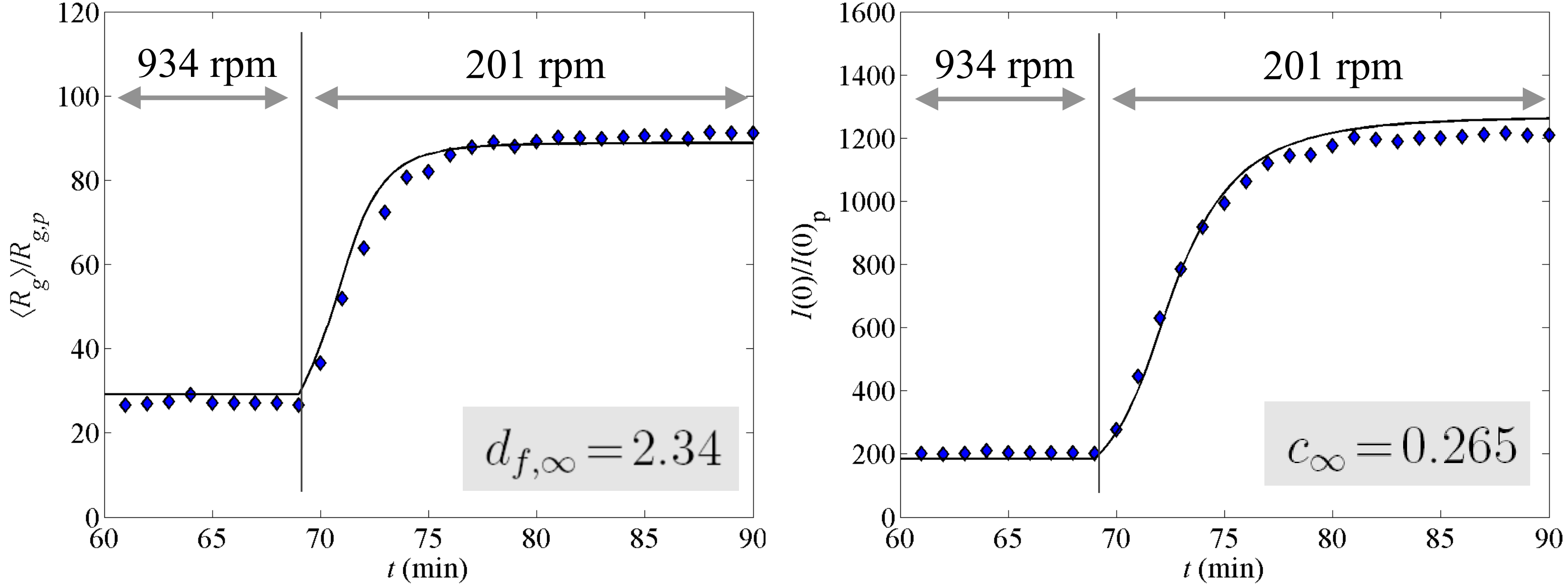




Backup Slides

Final fractal dimension

Regrowth upon a reduction in the stirring → PBE model w/ breakage and constant d_f



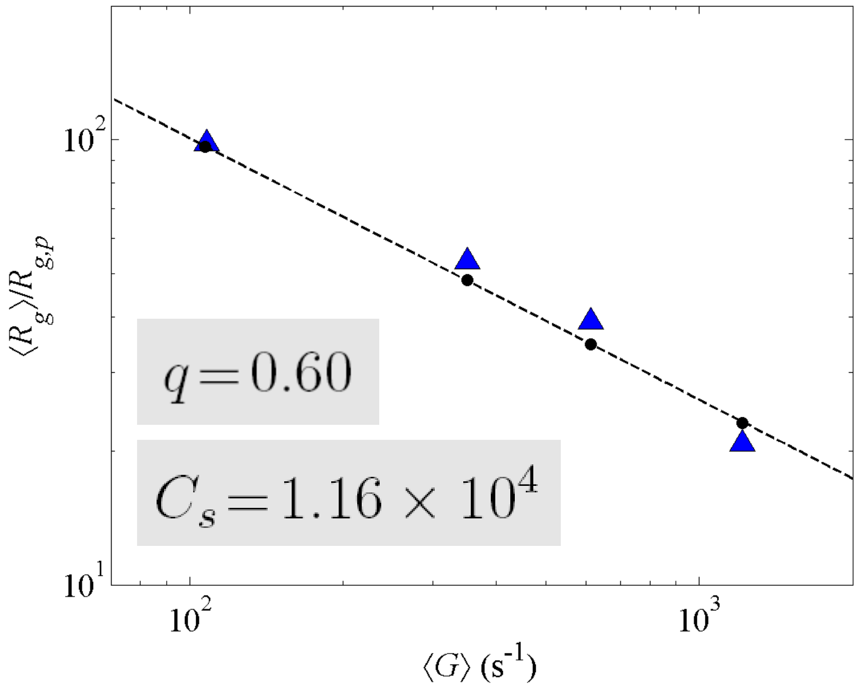
Breakage parameter

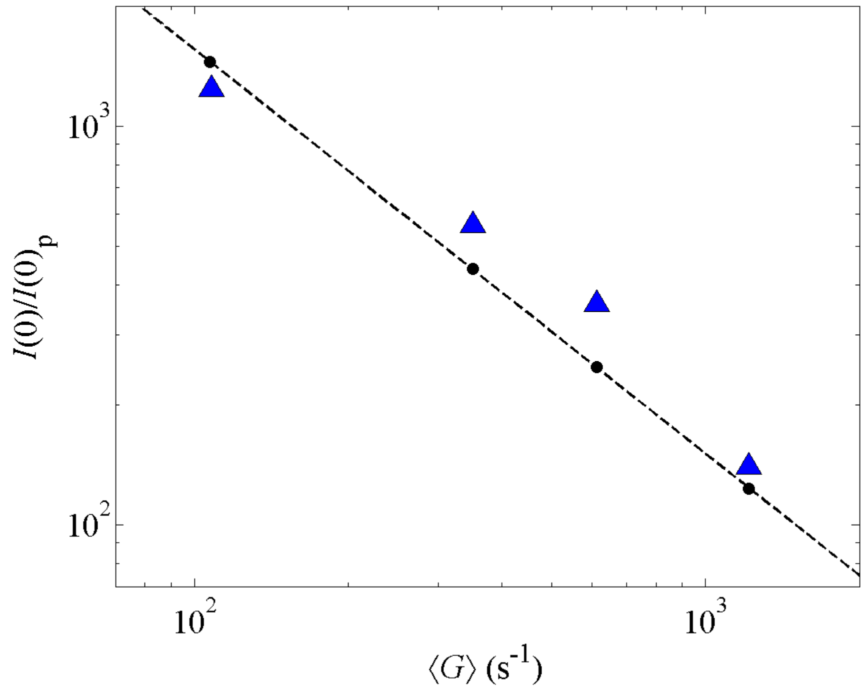
Steady state aggregate sizes at different rpm

PBE Model w/ Breakage

$d_{f,\infty} = 2.34$

$c_\infty = 0.265$

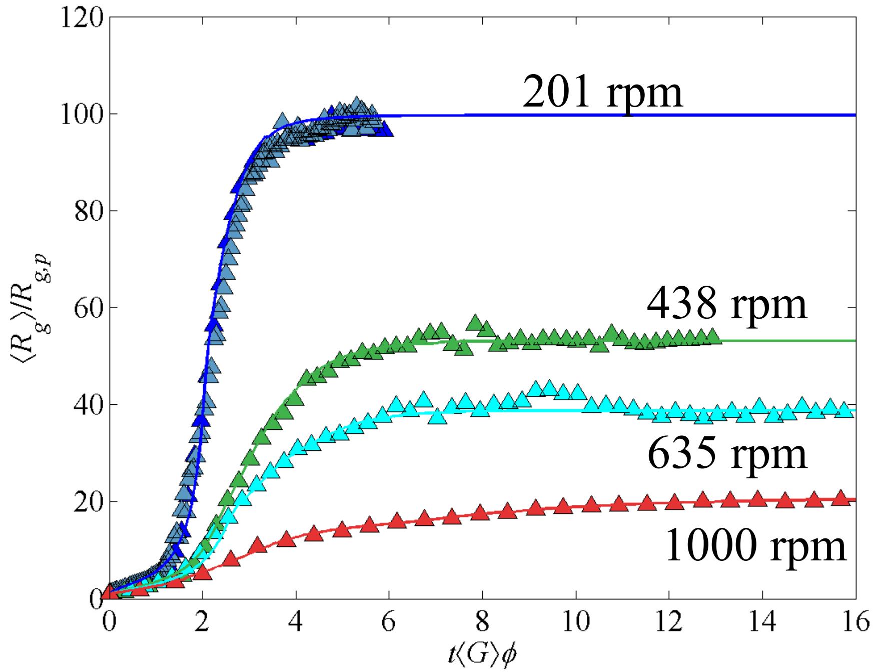


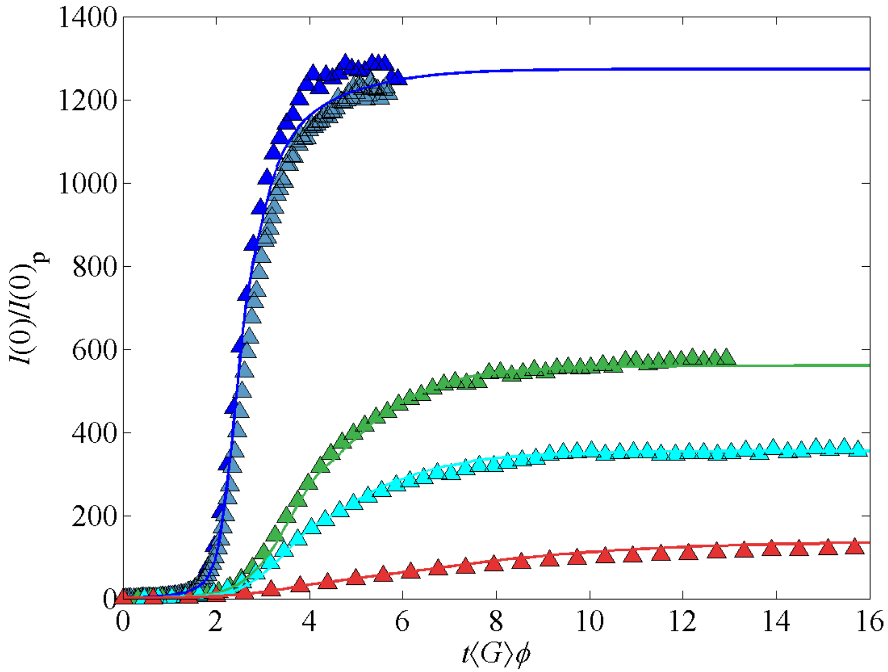


$$i_{cr} = C_s \varepsilon^{-q}$$

Backup Slides

Evolution of df and breakage param





- Fitting independent time evolution of d_f, c, *and* q