Numerical simulation of aggregate breakup in bounded and unbounded turbulent flows

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European Research Council
Established by the European Commission

10th European Fluid Mechanics Conference EFMC 10
Copenhagen, September 14-18, 2014

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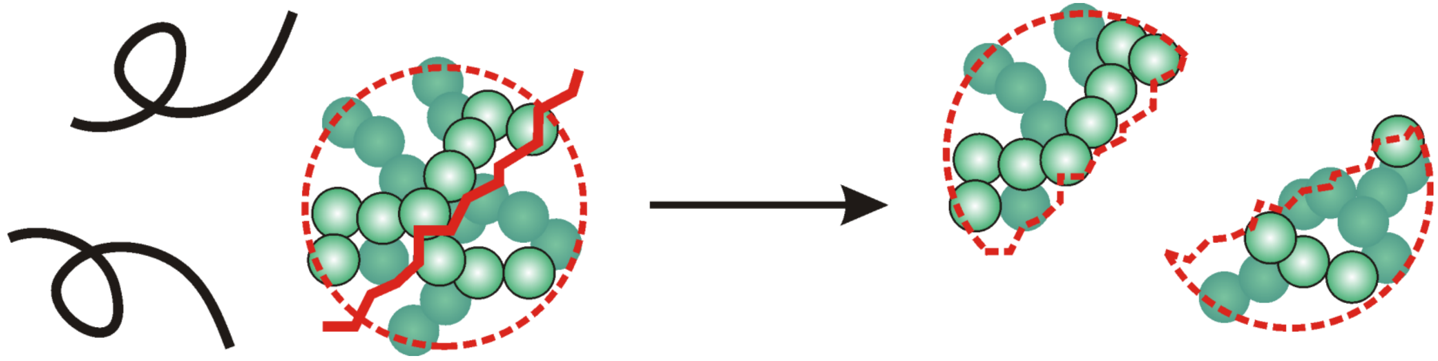
Breakup of aggregates



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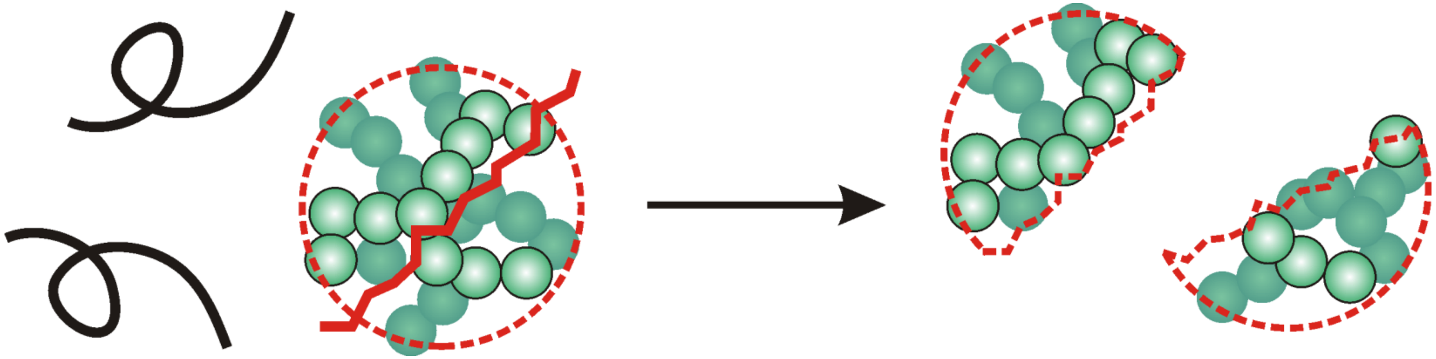
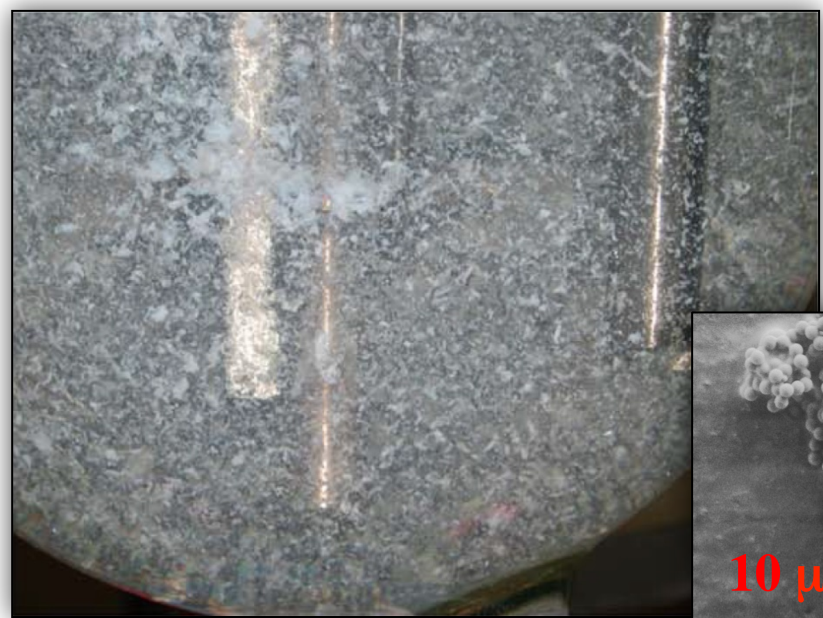
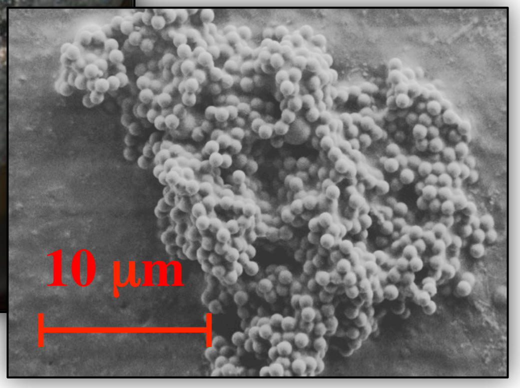






- Processing of industrial colloids (polymers, metal oxides, minerals)
- Flocculation in waste water treatment
- Evolution and transport of sediments and suspended mater in natural waters

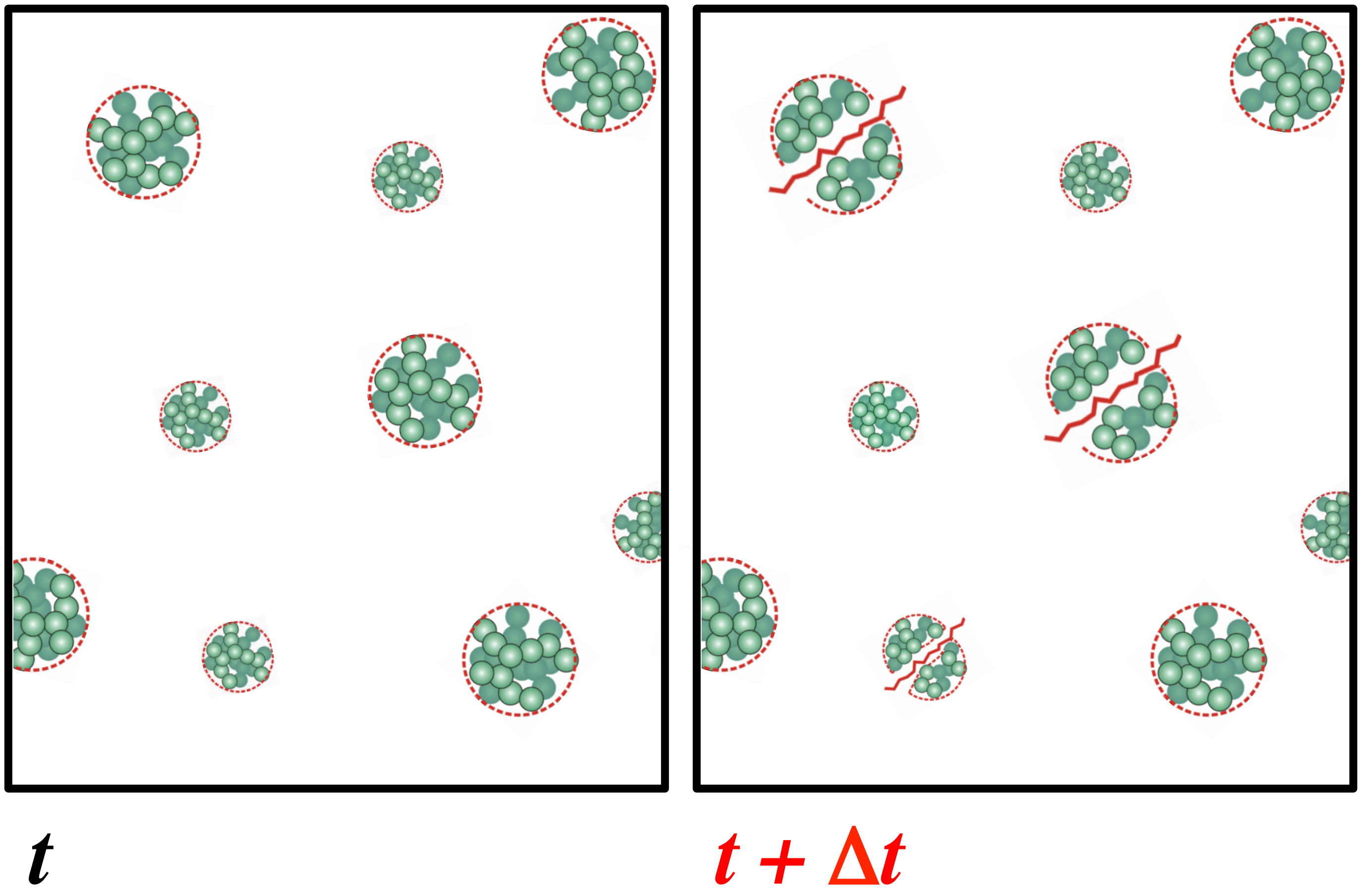
Pictures: M. Soos, D. Marchisio, J. Sefcik, *AIChE J.* (2013) and Soos, et al., *J. Colloid Interface Sci.* (2008)

Breakup of aggregates

This work:

Dynamics of aggregate breakup in bounded and unbounded flows through numerical simulations.

~ How many breakup events per unit time in a turbulently stirred suspension



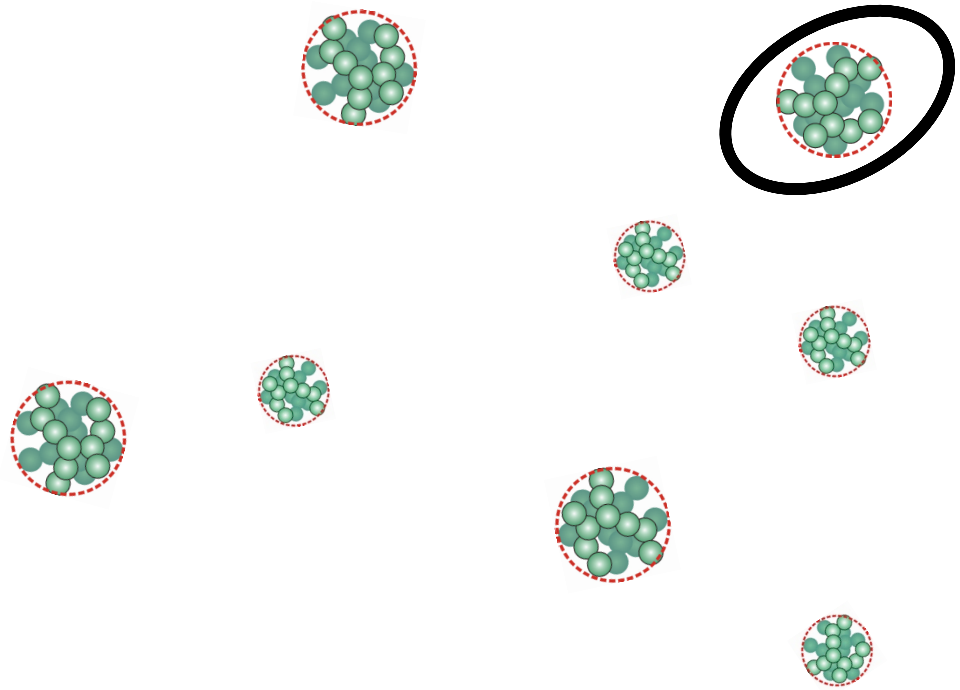
Numerical experiments

$$d \ll \eta$$

$$\rho_a \sim \rho_f$$

- Aggregate size small with respect to η.

  Aggregate density $\rho_a \approx \rho_f$



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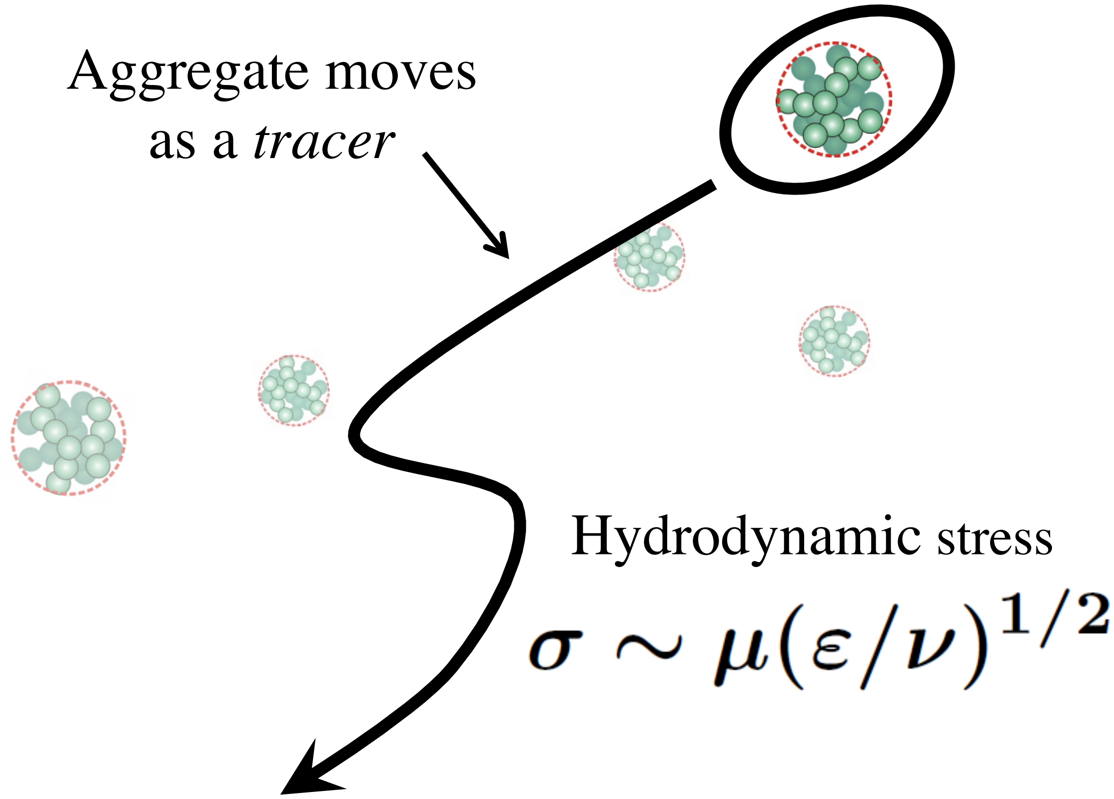

Numerical experiments

- Aggregate size small with respect to η.

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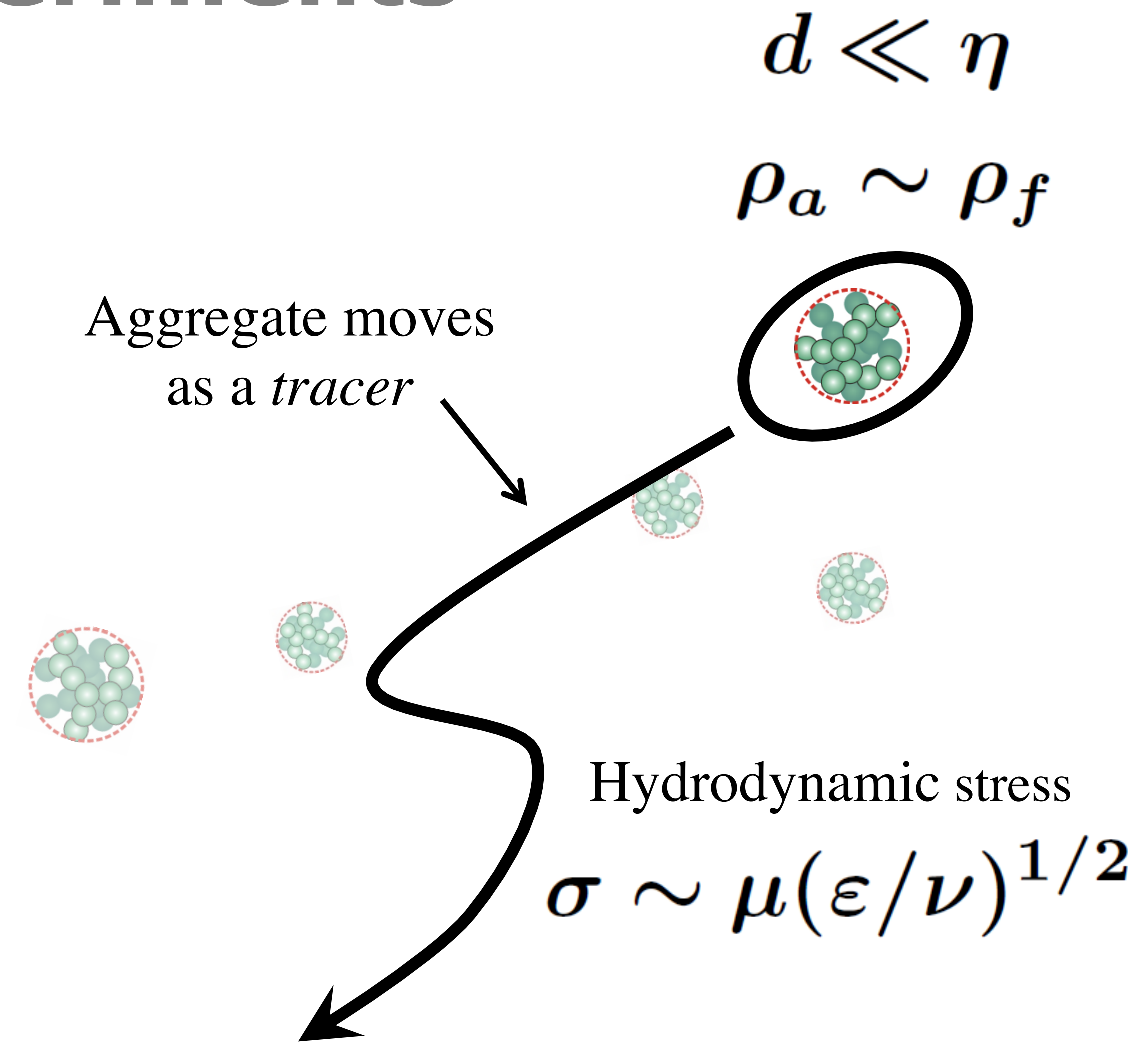
- Instant breakup when hydrodynamic stress exceeds critical stress σ_{cr}

- Critical stress σ_{cr}:

$$\sigma_{\mathrm{cr}} \sim d^{-q}$$



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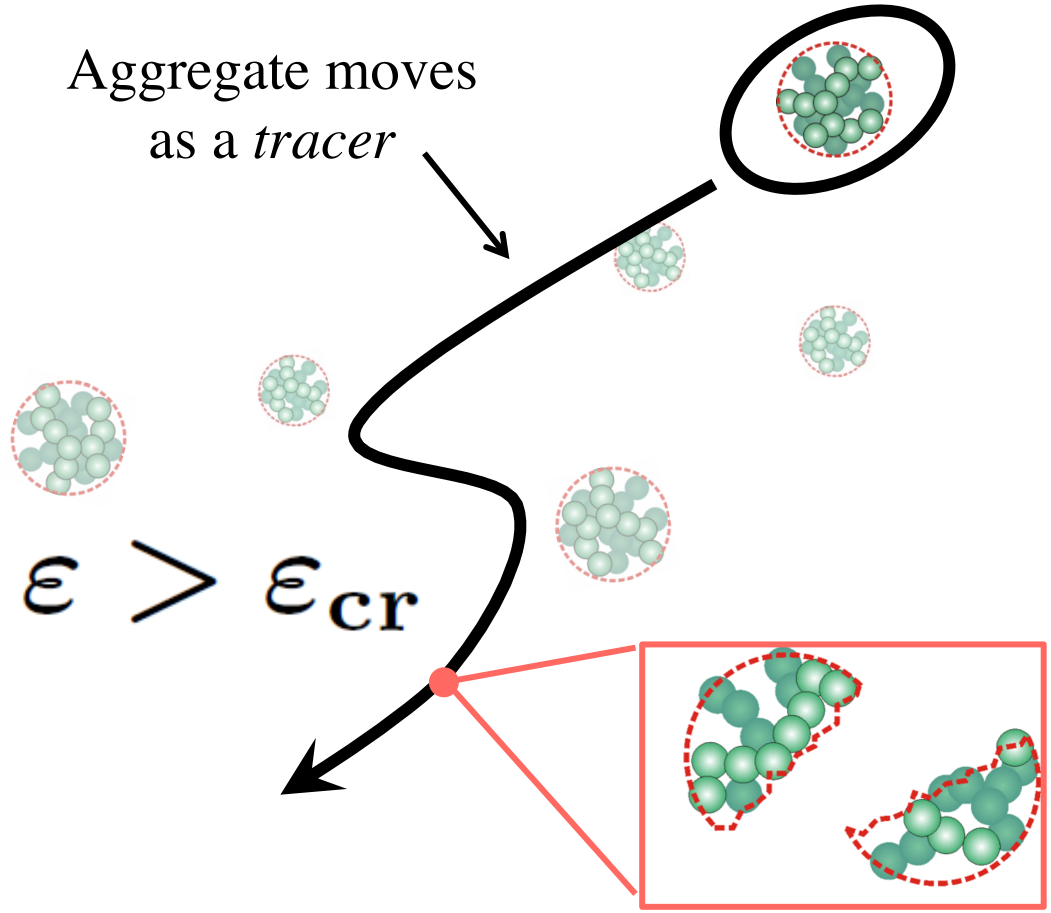


$$\varepsilon > \varepsilon_{\mathrm{cr}}$$

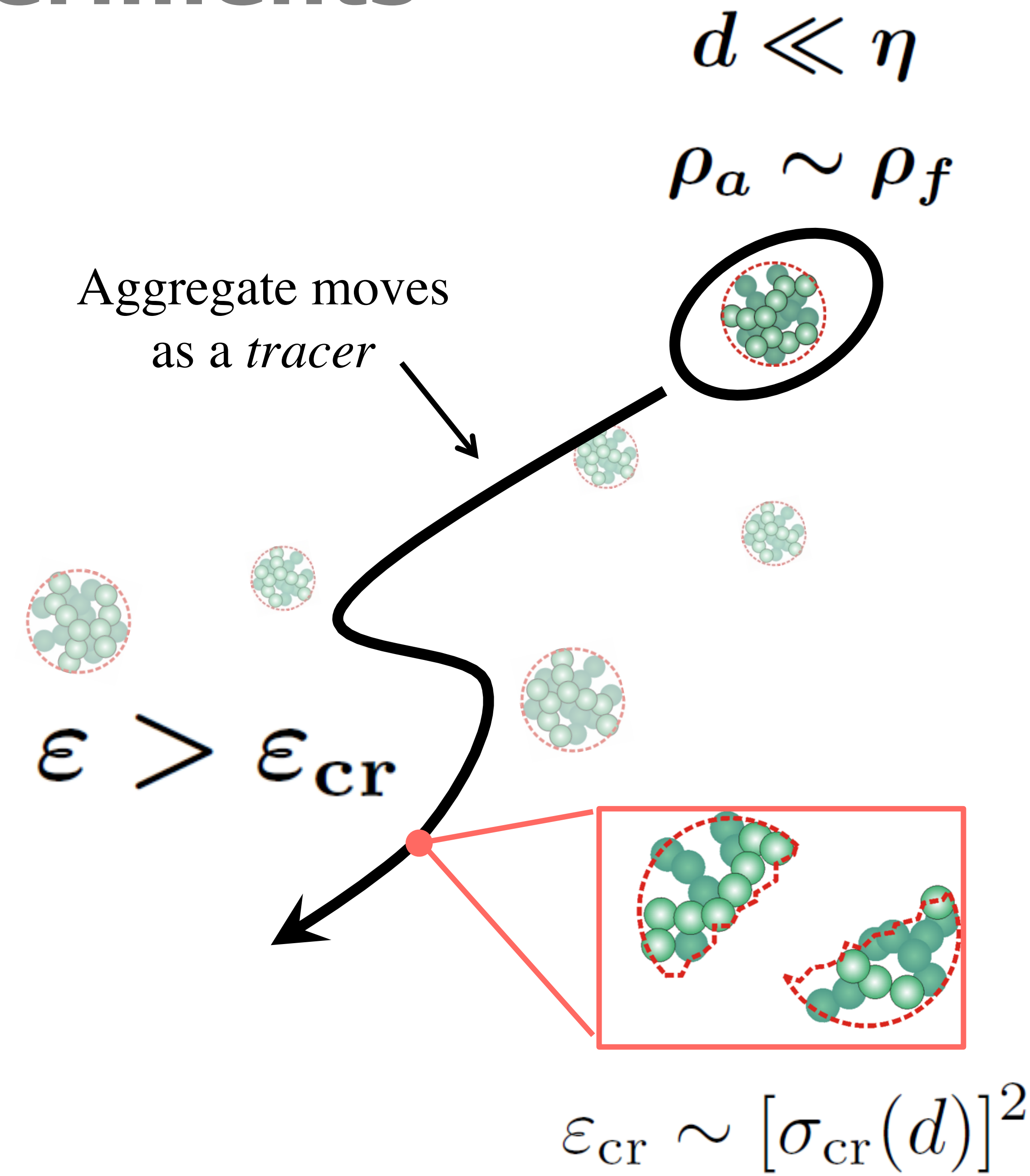
$$\varepsilon_{\mathrm{cr}} \sim [\sigma_{\mathrm{cr}}(d)]^2$$

Matthäus Bäbler, babler@kth.se

Numerical experiments

- Start with a stationary turbulent flow.
- At time t_0, release aggregate at random in a certain region of the flow.
- Follow the aggregate until the first occurrence of $\varepsilon > \varepsilon_{cr}$.
- The time from release until breakup defines the exit-time $\tau_{\varepsilon_{cr}}$
- Breakup-rate:

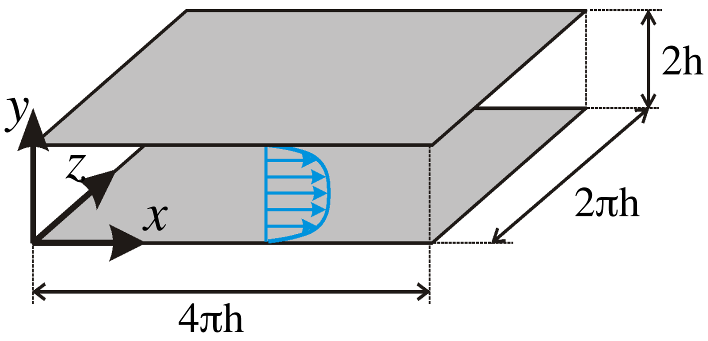
$$f_{\varepsilon_{cr}} = \frac{1}{\langle \tau_{\varepsilon_{cr}} \rangle}$$



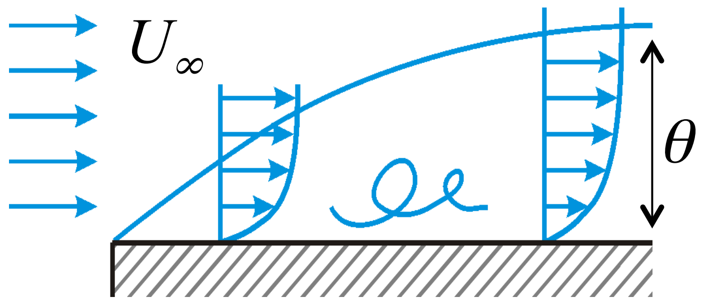
M.U. Babler, L. Biferale, A.S. Lanotte, *PRE* (2012)

Flow configurations

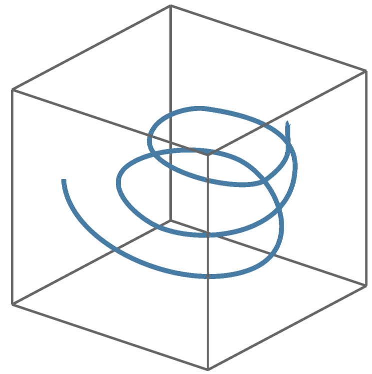
Channel flow



Developing boundary layer flow



H.I.T.



- Periodic in x and z, Resolution 128×128×129
- $R_\tau = u_\tau h/\nu = 150$ (u_τ = shear velocity)

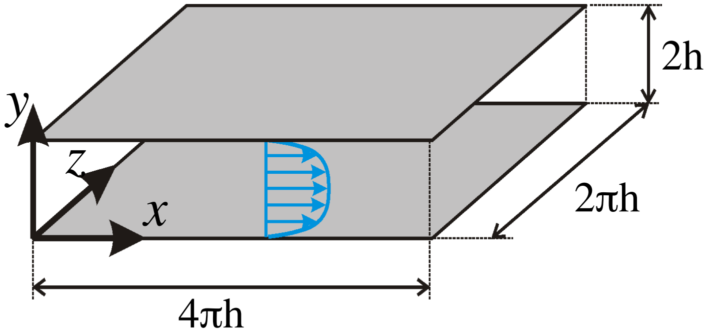
- Resolution 4096×301×384
- $R_\theta = U_\infty \theta/\nu = 200\text{-}2500$ (θ=momentum-loss thickness)

- Resolution 2048^3
- $Re_\lambda = 400$

E. Pitton, C. Marchioli, V. Lavezzo, A. Soldati, F. Toschi, *Phys. Fluids* **24** (2012) 073305
G. Sardina, P. Schlatter, F. Picano, C.M. Casciola, L. Brandt, D.S. Henningson, *J. Fluid Mech.* **706** (2012) 584
J. Bec, L. Biferale, A.S. Lanotte, A. Scagliarini, F. Toschi, *J. Fluid Mech.* **645** (2010) 497

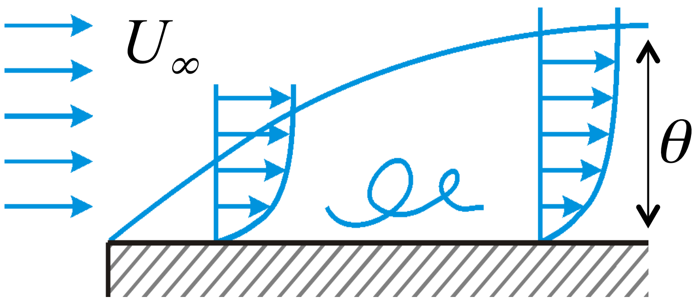
Seeding regions

Channel flow



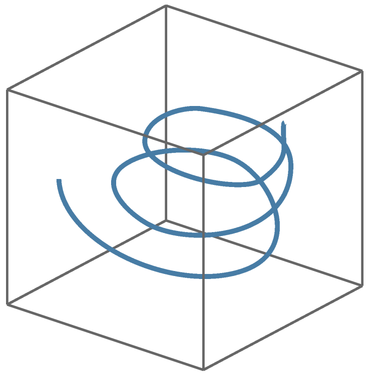
- Center-plane
- Near-wall region

Developing boundary layer flow



- Inside the BL
- Outside the BL

H.I.T.

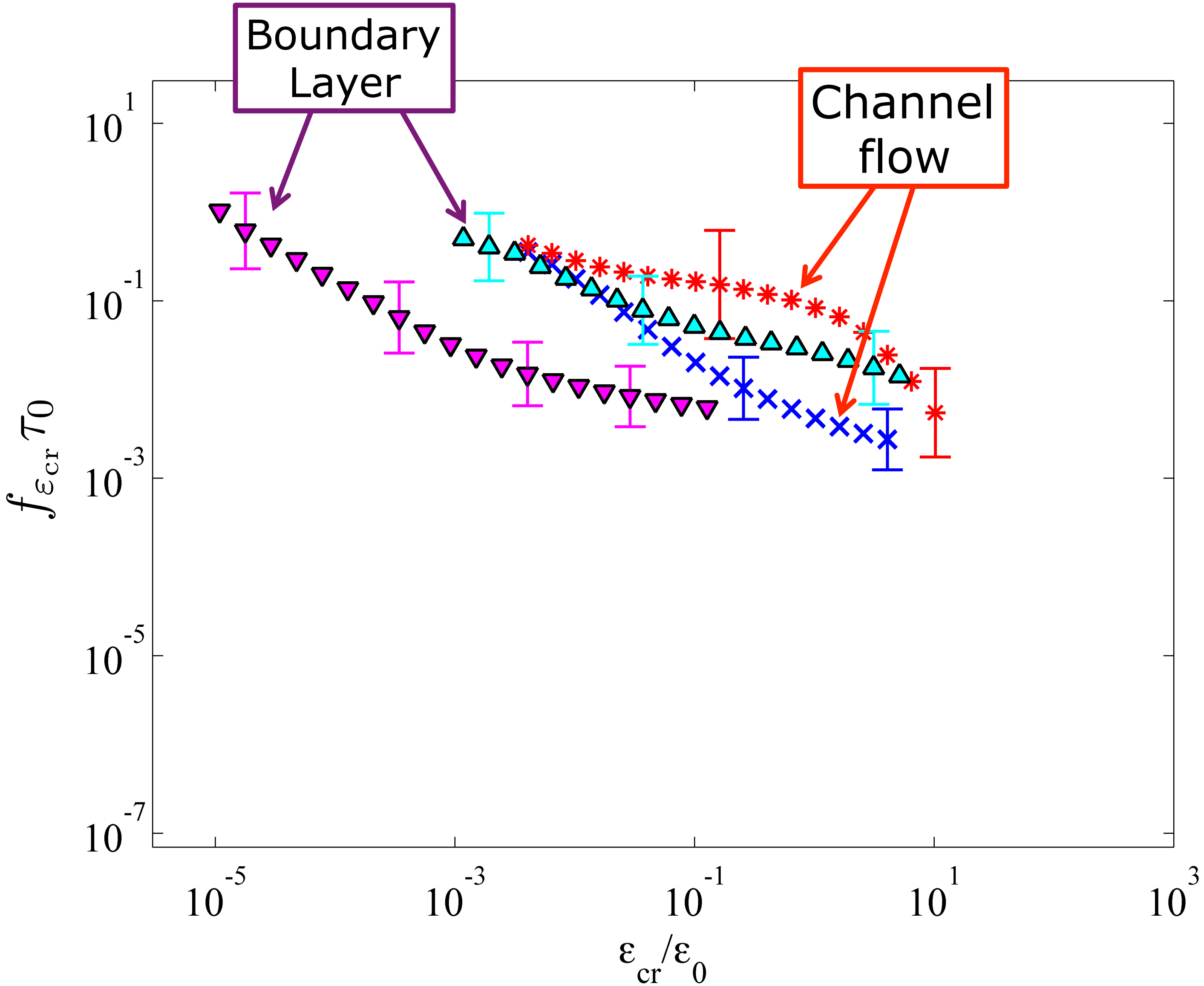


Aggregates are released homogenously

Results

- **Channel flow**
  ε_0=volume average
  $\tau_0=(\nu/\varepsilon_0)^{1/2}$

- **Boundary layer**
  ε_0=volume average
  inner seeding region
  $\tau_0=(\nu/\varepsilon_0)^{1/2}$



Babler *et al.*, *J. Fluid Mech. Submitted* (2014)

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- **H.I.T.**
  ε_0=mean dissipation
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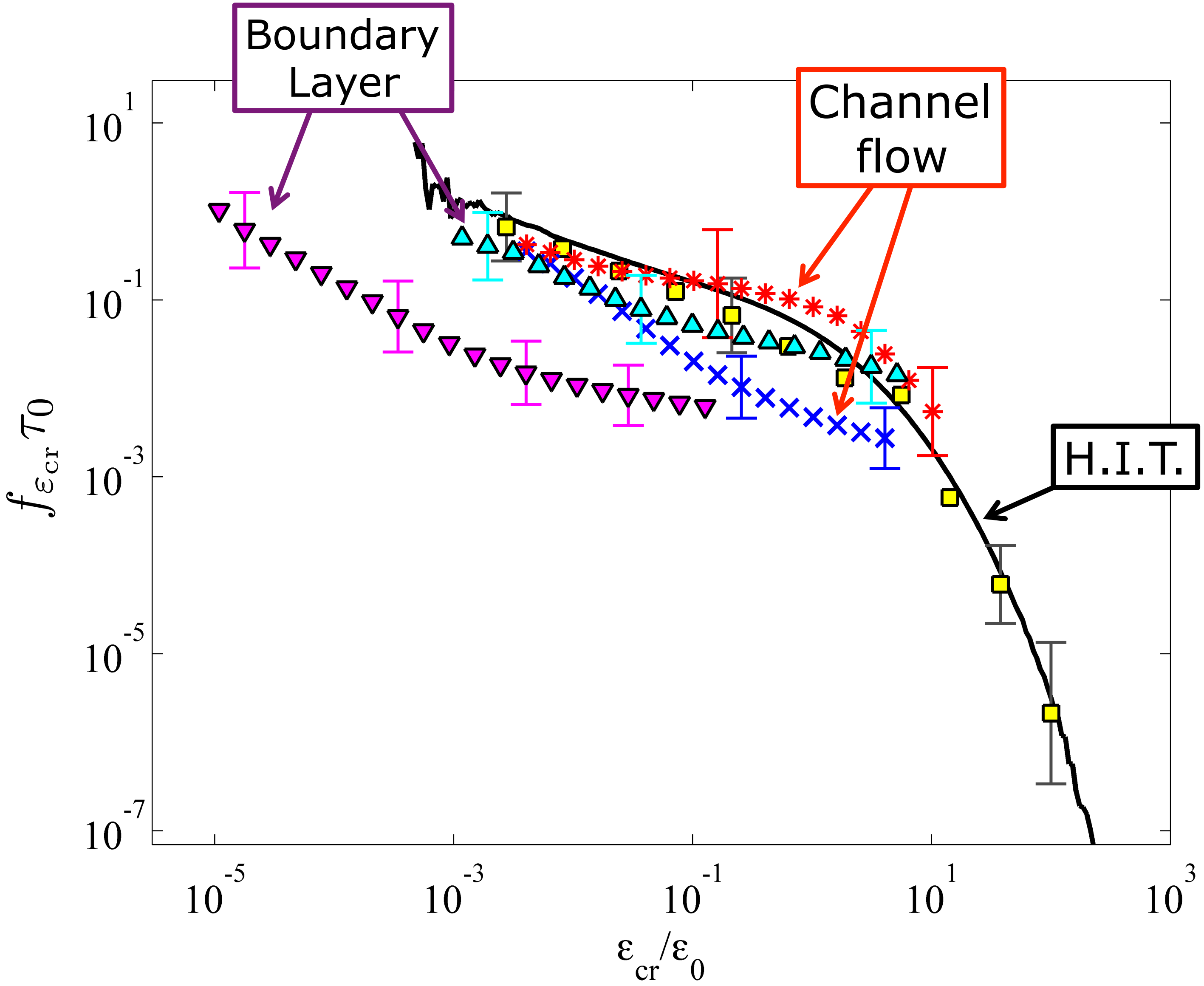

Babler *et al.*, *J. Fluid Mech. Submitted* (2014)

Results

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- **Boundary layer**
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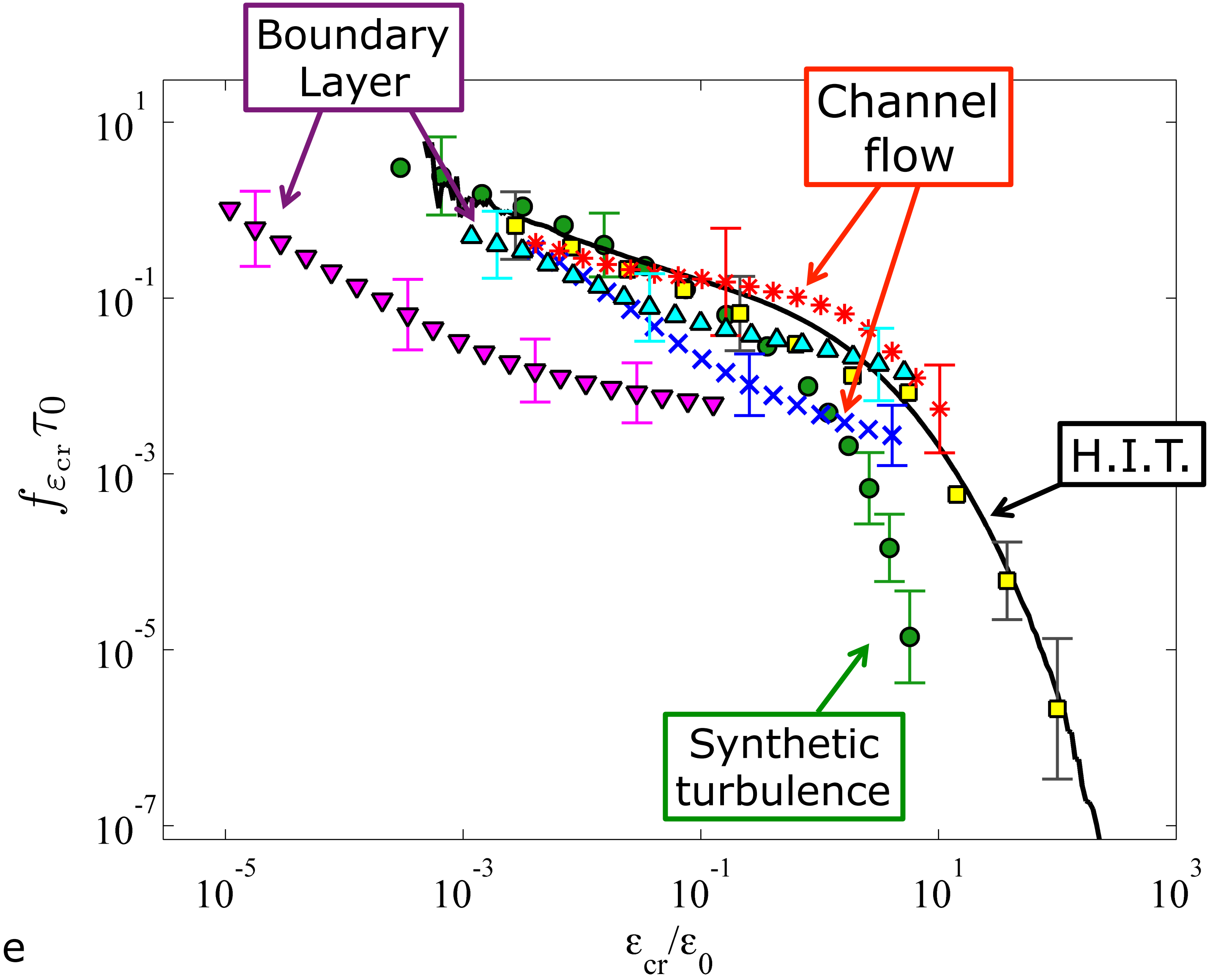
  inner seeding region
  $\tau_0=(\nu/\varepsilon_0)^{1/2}$
- **H.I.T.**
  ε_0=mean dissipation
  $\tau_0=(\nu/\varepsilon_0)^{1/2}$
- **Synthetic turbulence**
  ε_0=mean dissipation
  τ_0=acceleration timescale



Babler *et al.*, *J. Fluid Mech. Submitted* (2014)

Conclusions

- Breakup in bounded flows is the result of two competing effects: the systematic influence of the mean flow profile and the intermittent burst caused by turbulent fluctuations.
- Breakup of weak aggregates exhibits a qualitatively similar power law behavior among the different flows. Inspection shows that weak aggregates break up in the close vicinity of the point of release. Fluctuations causing breakup are independent of the flow configuration.
- Breakup of strong aggregates is influenced by the mean flow profile and depends on the flow configuration.

Babler et al. (2014) arxiv:1406.2842

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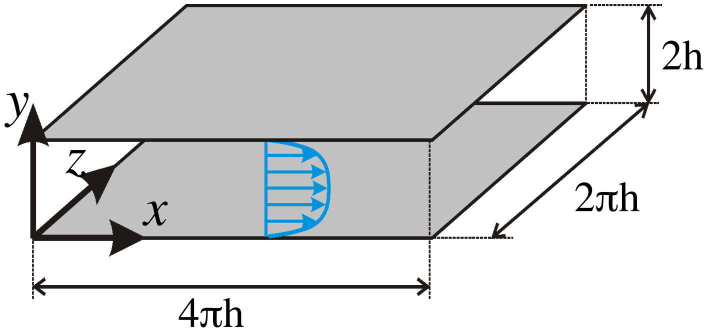
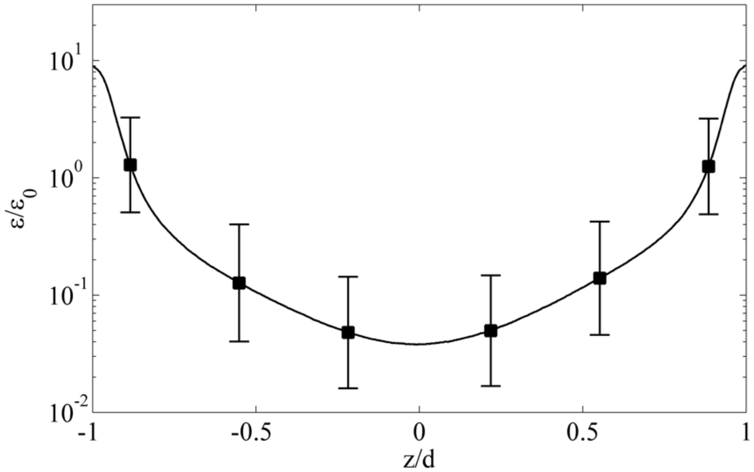
Backup Slide

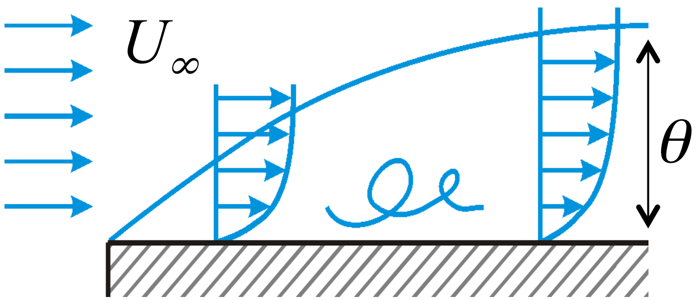
Flow configurations

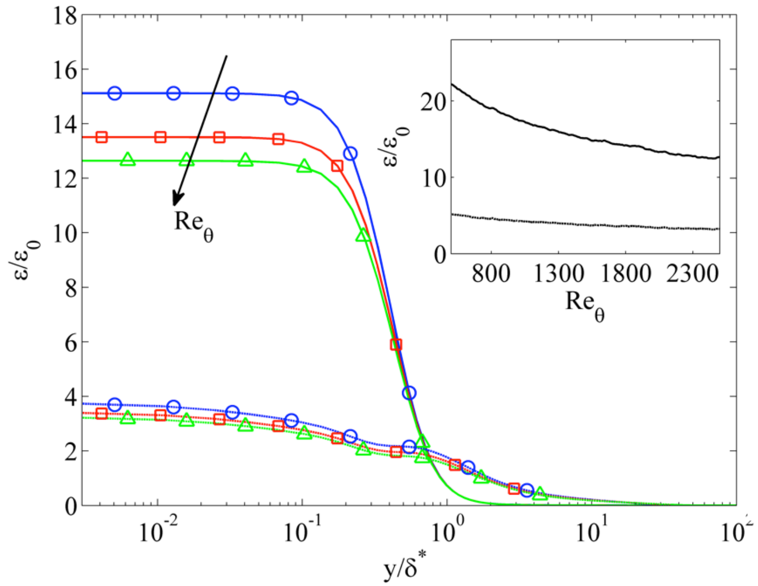
Channel flow





Developing boundary layer flow





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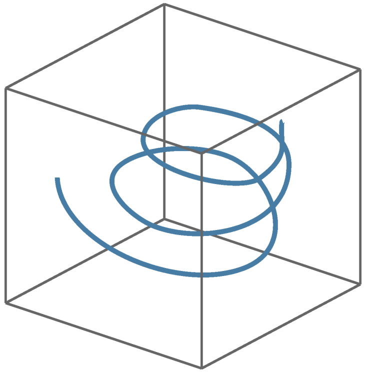

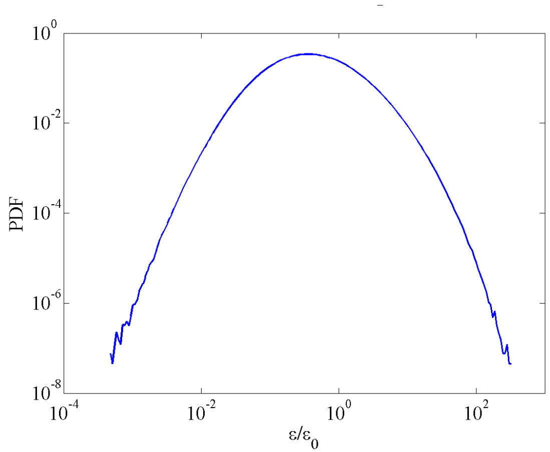

Breakup location

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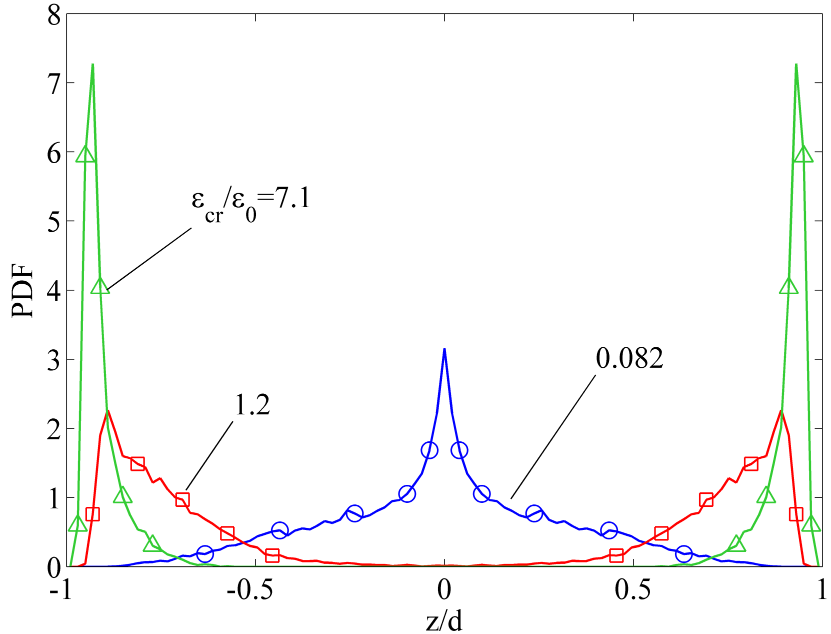
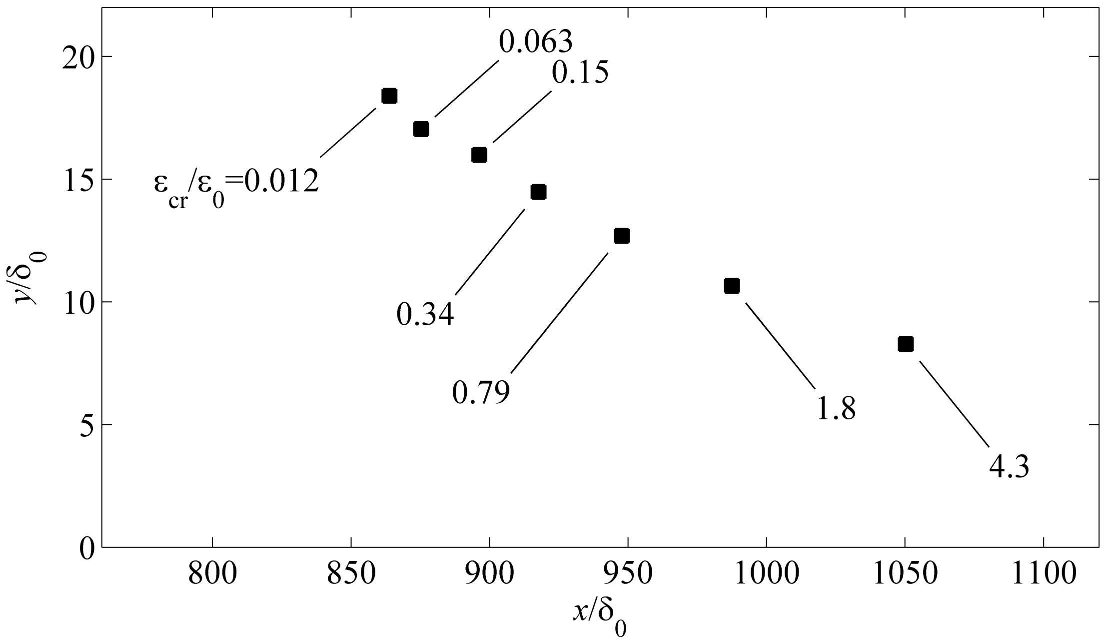
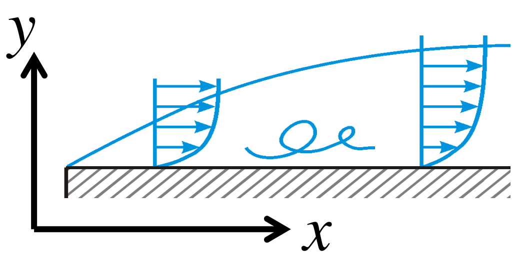


Breakup location in the channel flow.





Breakup location in the boundary layer flow

Aggregate trajectories

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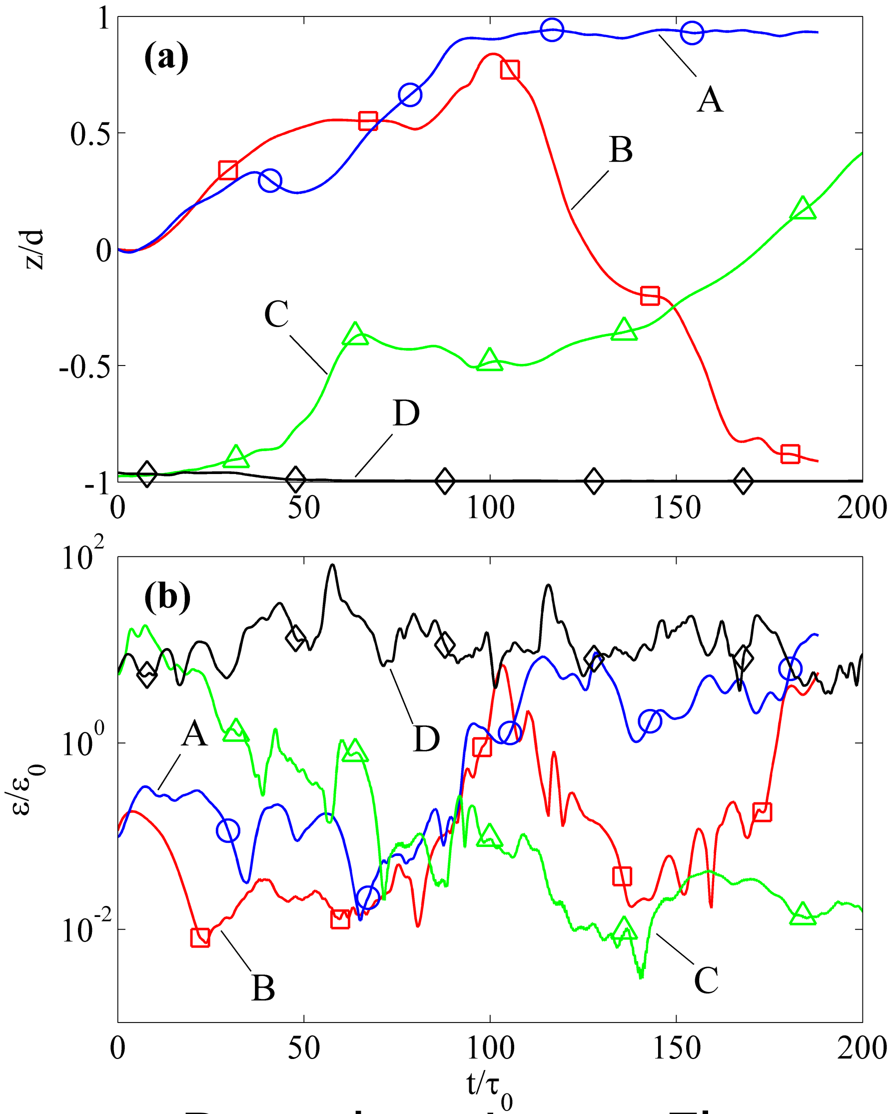
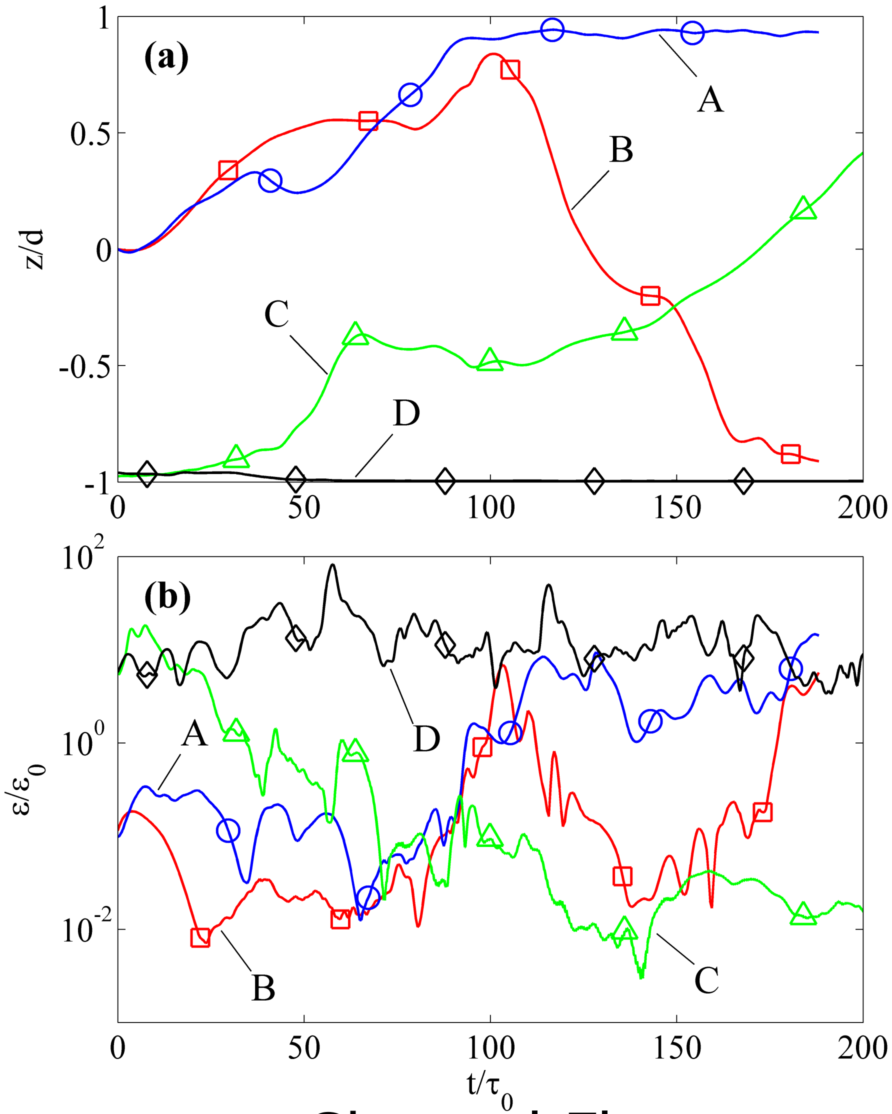


Boundary Layer Flow



Channel Flow

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Synthetic Turbulence

$$\boldsymbol{u}(\boldsymbol{x},t) = \sum_{\boldsymbol{k}} \hat{\boldsymbol{u}}'_{\boldsymbol{k}}(t) e^{i\boldsymbol{k}\boldsymbol{x}}$$

$$\mathrm{d}\hat{\boldsymbol{u}}_{\boldsymbol{k}} = \hat{\boldsymbol{a}}_{\boldsymbol{k}} \mathrm{d}t$$

$$\mathrm{d}\hat{\boldsymbol{a}}_{\boldsymbol{k}} = -\frac{\hat{\boldsymbol{a}}_{\boldsymbol{k}}}{t_\eta}\mathrm{d}t - \frac{\hat{\boldsymbol{u}}_{\boldsymbol{k}}}{t_\eta t_L}\mathrm{d}t + \sqrt{\frac{2\sigma_{\boldsymbol{k}}^2}{t_\eta^2 t_L}}\mathrm{d}\boldsymbol{W}$$

$$Re_\sigma \sim t_L / t_\eta$$