Breakup of inertial aggregates in homogeneous turbulence

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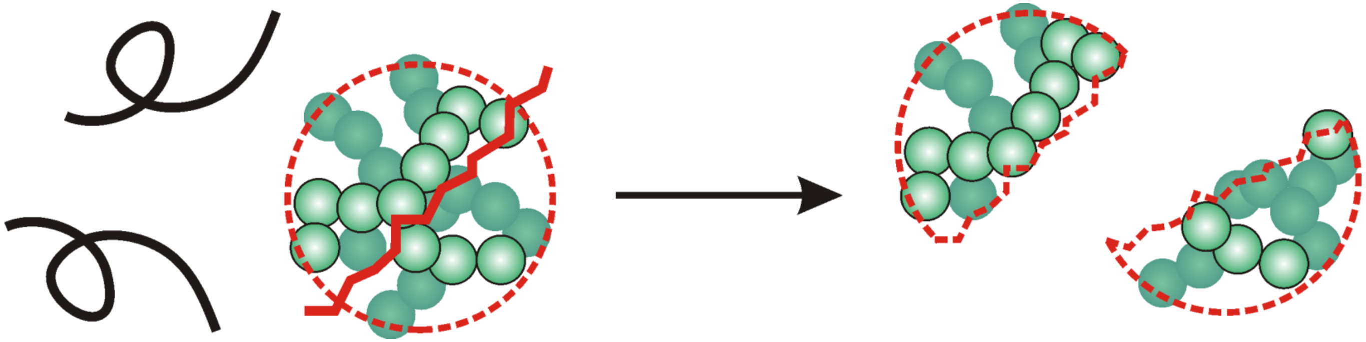
Breakup of aggregates



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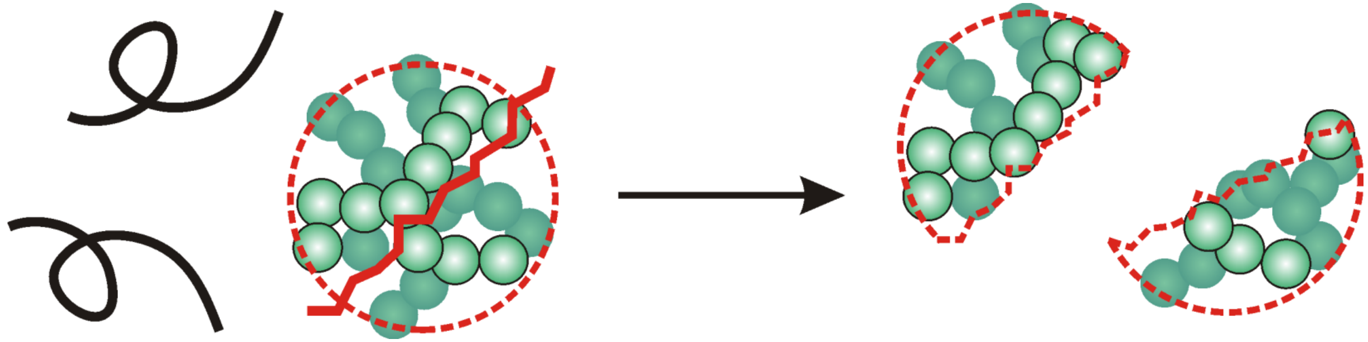
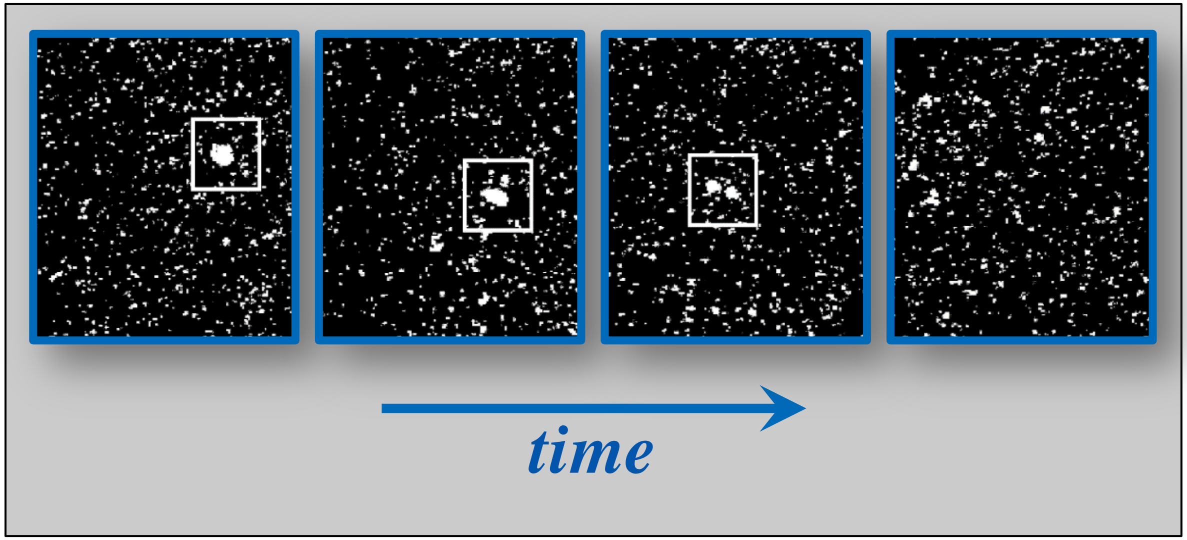


Previous work:

Tracer-like aggregates in different flows configurations

- Numerical experiments (Babler *et al.*, 2012, 2015)
- PTV with colloidal aggregates (Saha *et al.*, 2014, 2015 *sub.*)



Pictures: D. Saha, *et al.*, *Langmuir* (2015*sub.*) and Soos, *et al.*, *J. Colloid Interface Sci.* (2008)

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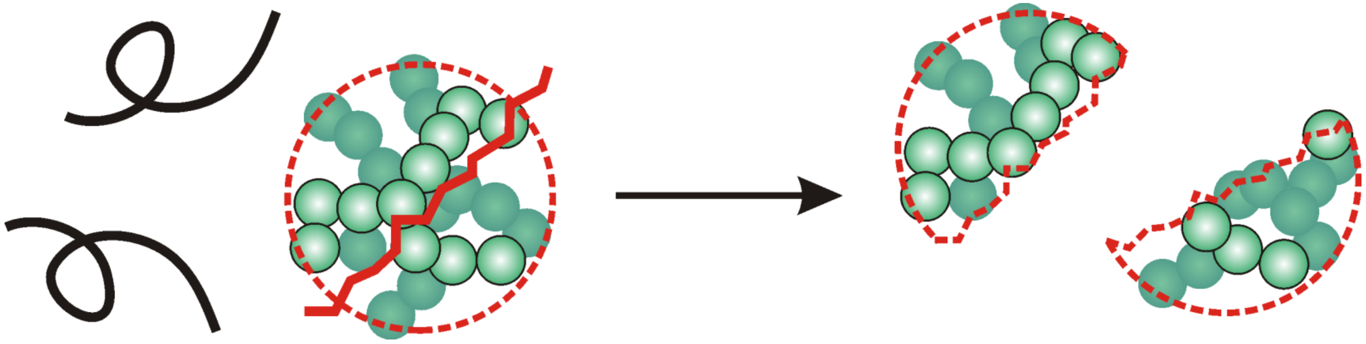
Breakup of aggregates



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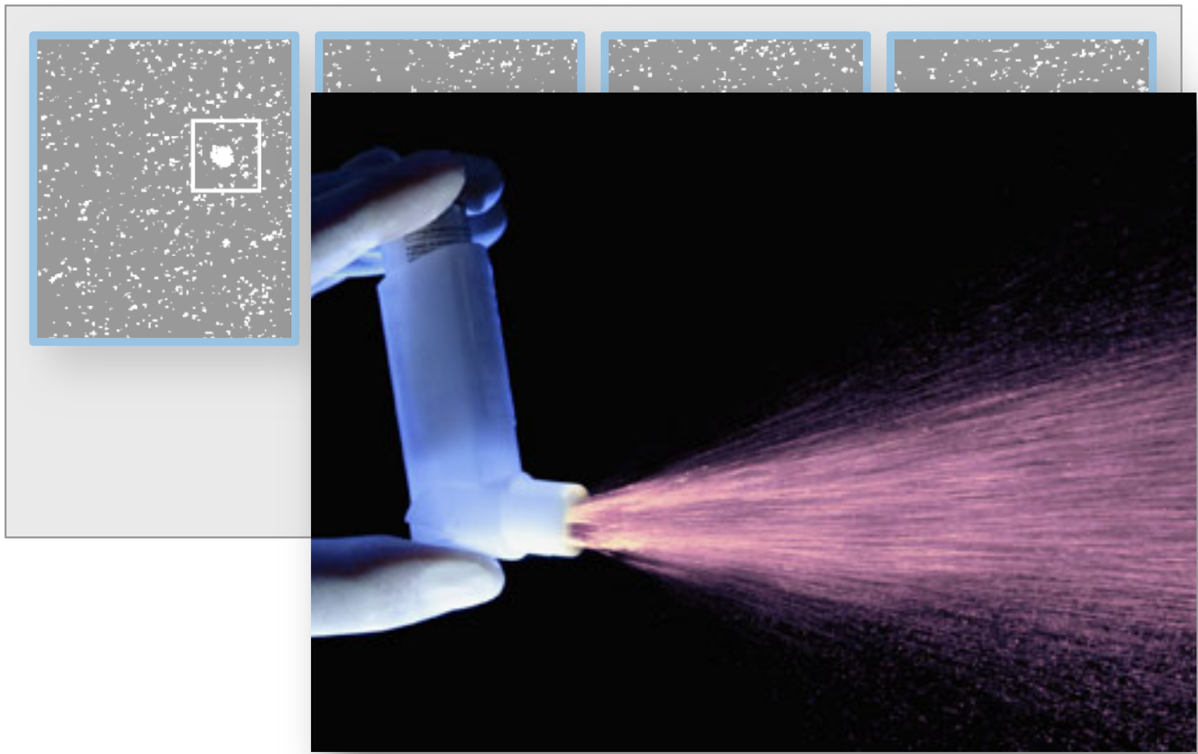
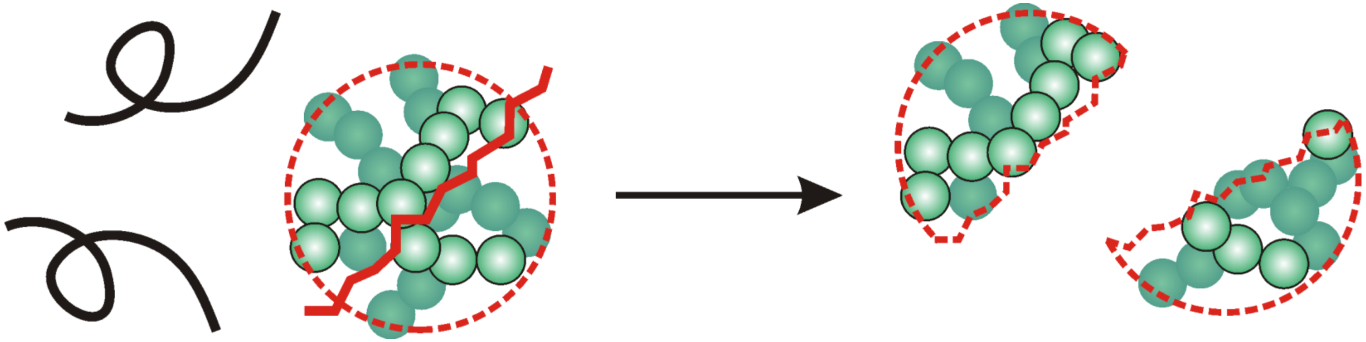
***This work*:**

Small & heavy aggregates in HIT



Picture: Getty images (2015-03-22)

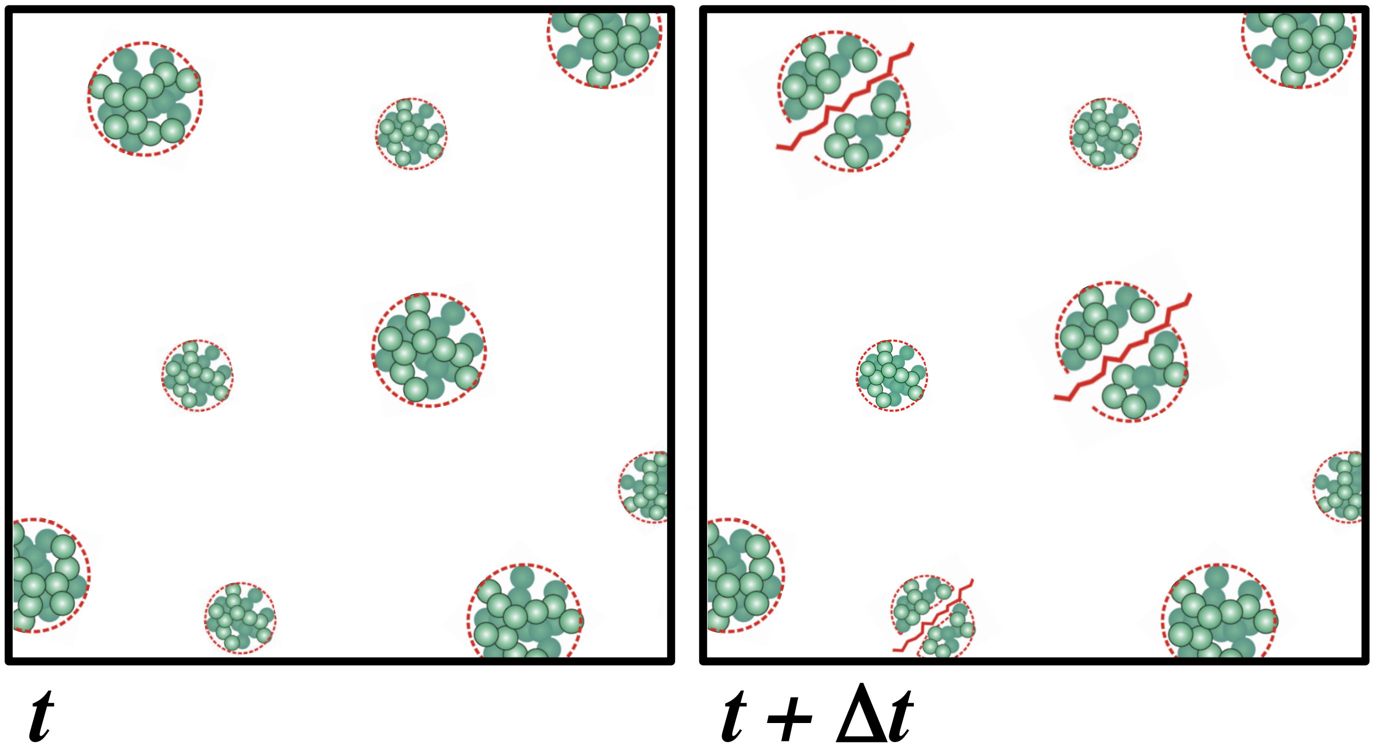
Breakup of aggregates



Aim of this work:

Dynamics of breakup of small and heavy aggregates caused by turbulent fluid motions

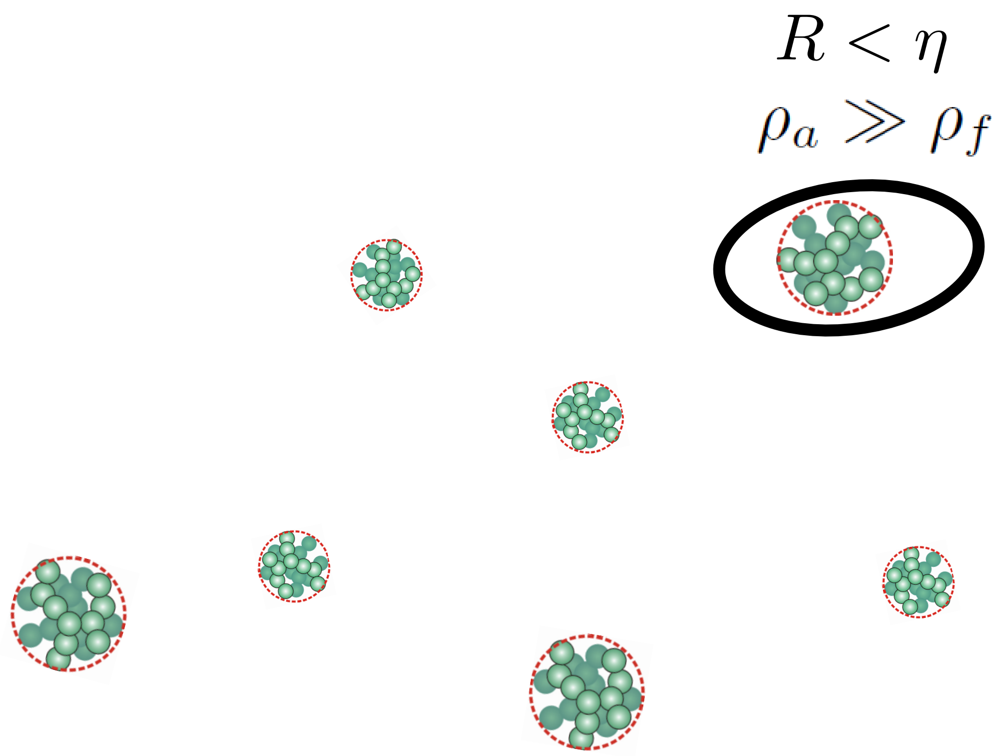
$\sim$ *How many breakup events per unit time*



Numerical framework

- Stationary homogeneous isotropic turbulent flow, loaded with few aggregates

- Small & heavy aggregates:
  - Aggregate size small with resect to η
  - Aggregate density large with respect to fluid density



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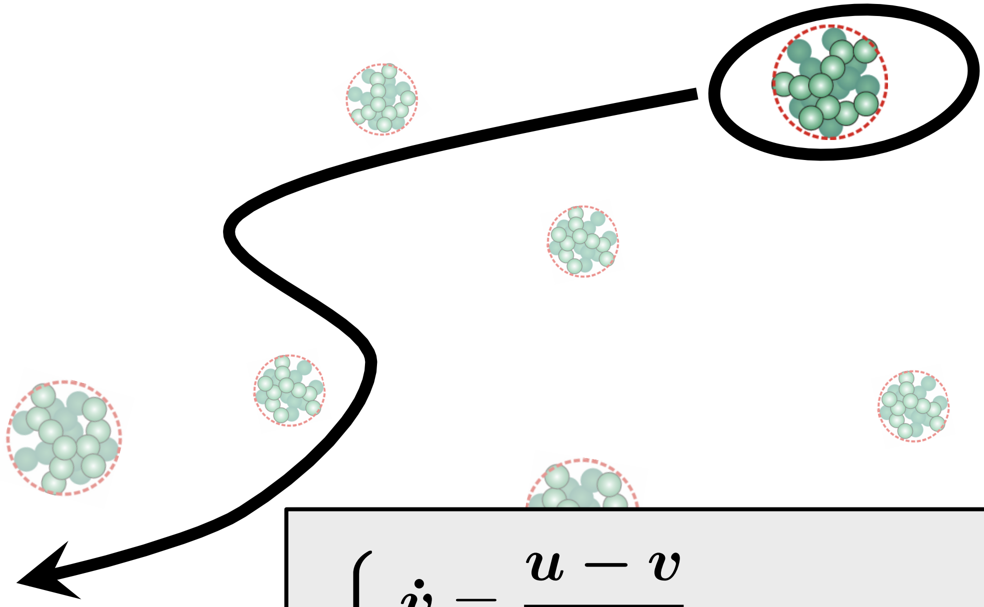
$R < \eta$

$\rho_a \gg \rho_f$



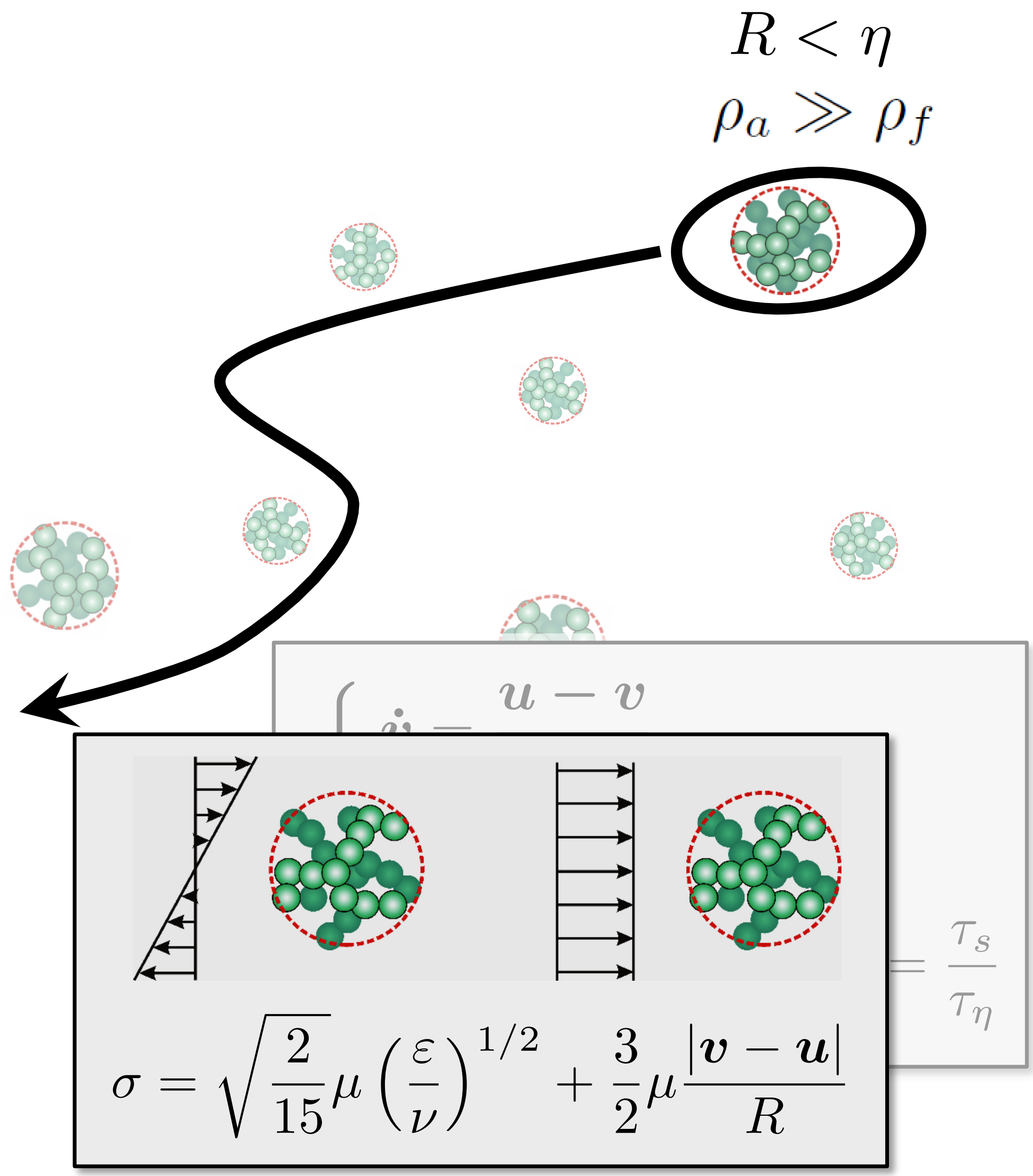
$$\begin{cases} \dot{\boldsymbol{v}} = \dfrac{\boldsymbol{u} - \boldsymbol{v}}{\tau_s} \\ \dot{\boldsymbol{x}} = \boldsymbol{v} \end{cases}$$

$$\tau_s = \frac{(2\rho_a + \rho_f)R^2}{9\rho_f \nu} \qquad St = \frac{\tau_s}{\tau_\eta}$$

Numerical framework

- Aggregates are broken due to due hydrodynamic stress acting on them

- *Brittle limit*: Aggregate break up when the hydrodynamic stress exceeds a critical value σ_{cr}



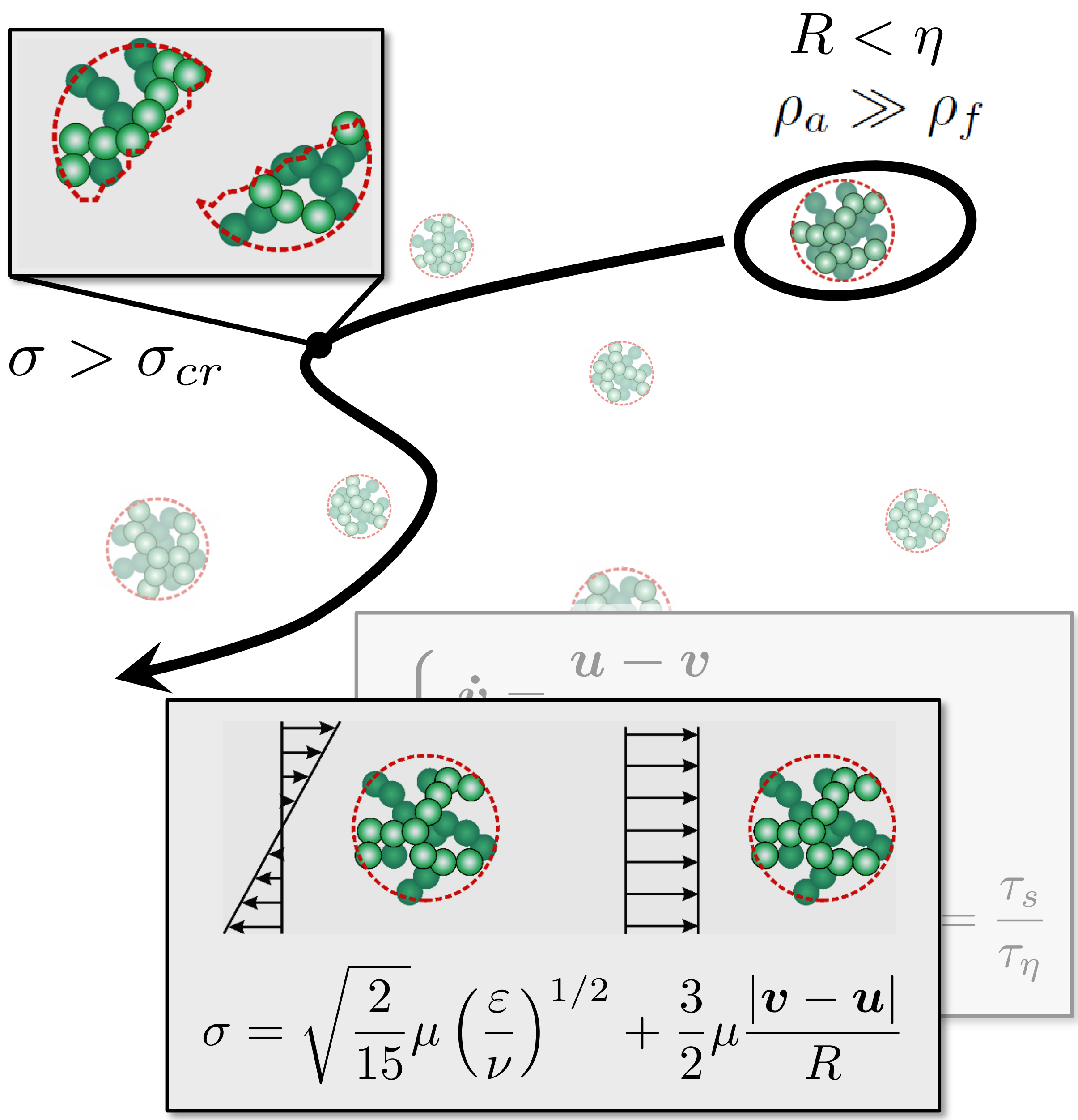
K.A. Kusters (1991), Bagster and Tomi (1974)

Numerical framework

- Aggregates are broken due to due hydrodynamic stress acting on them
- *Brittle limit*: Aggregate break up when the hydrodynamic stress exceeds a critical value σ_{cr}
- σ_{cr} is a characteristic for a given type of aggregates

$$\sigma_{\mathrm{cr}} \sim R^{-1/q}$$

$$q \approx 0.35 - 0.55$$



Harshe, *et al.*, *Langmuir* (2011), Zaccone, *et al.*, *PRE* (2009)

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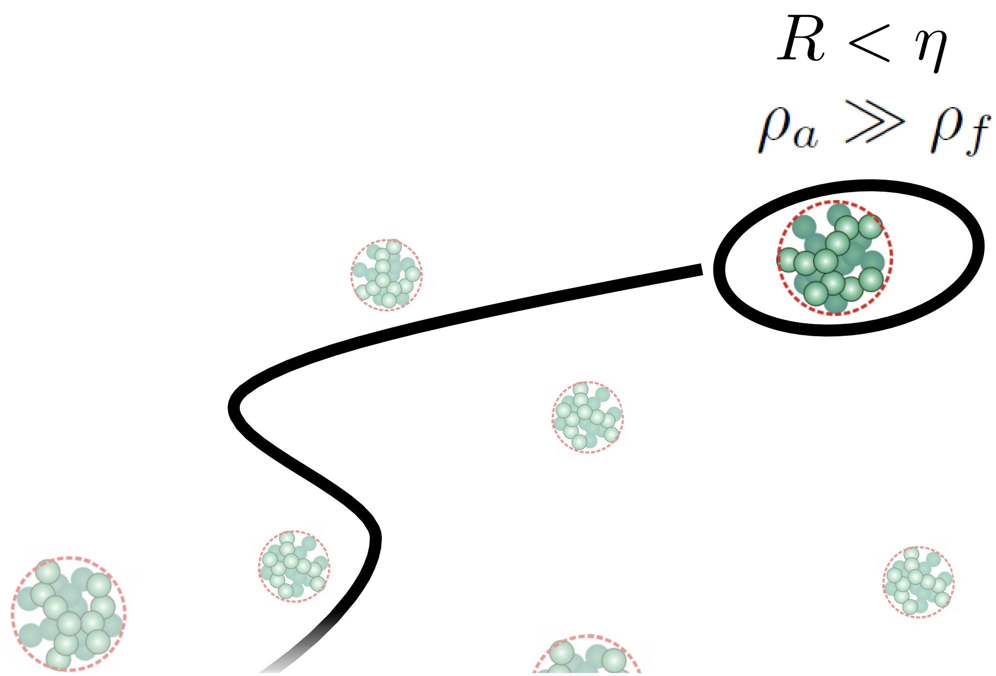
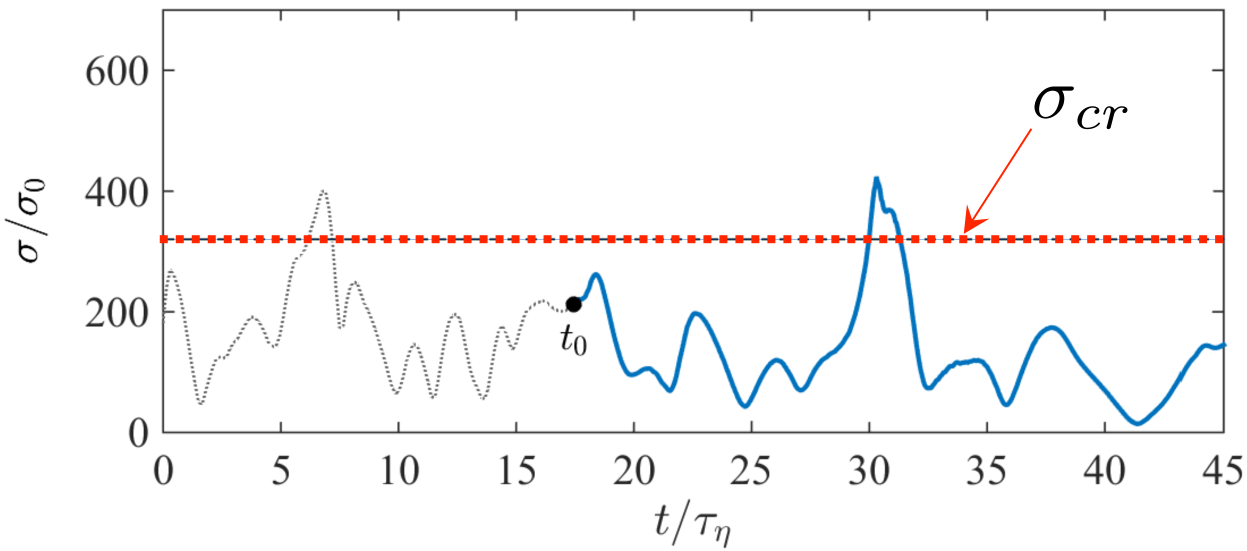
Numerical framework

- Upon release, we follow the aggregate until the first crossing of σ_{cr}





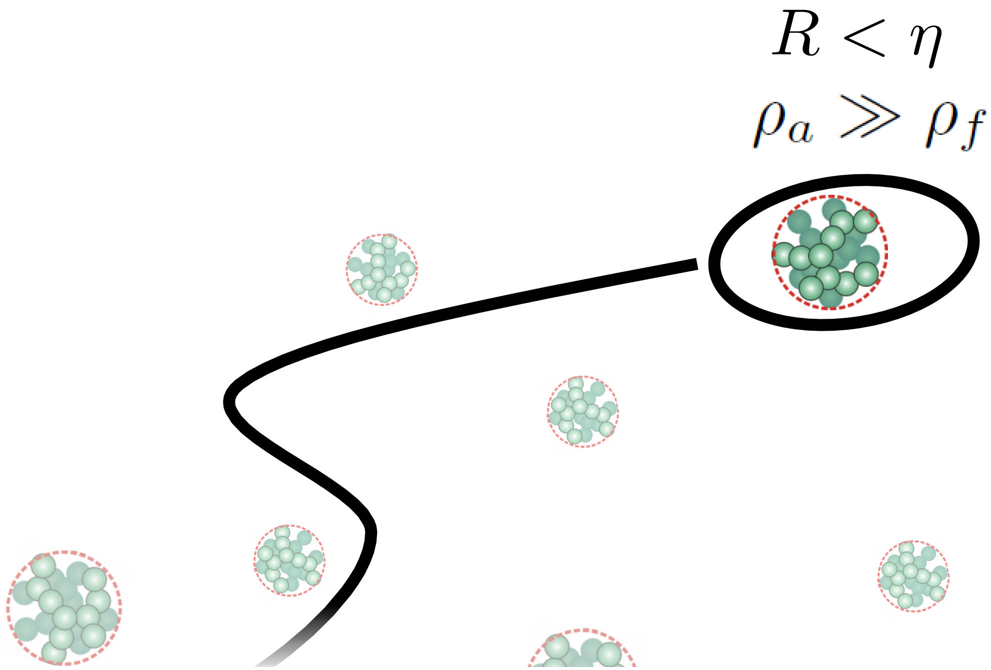
Babler, Biferale, Lanotte, *PRE* (2012)

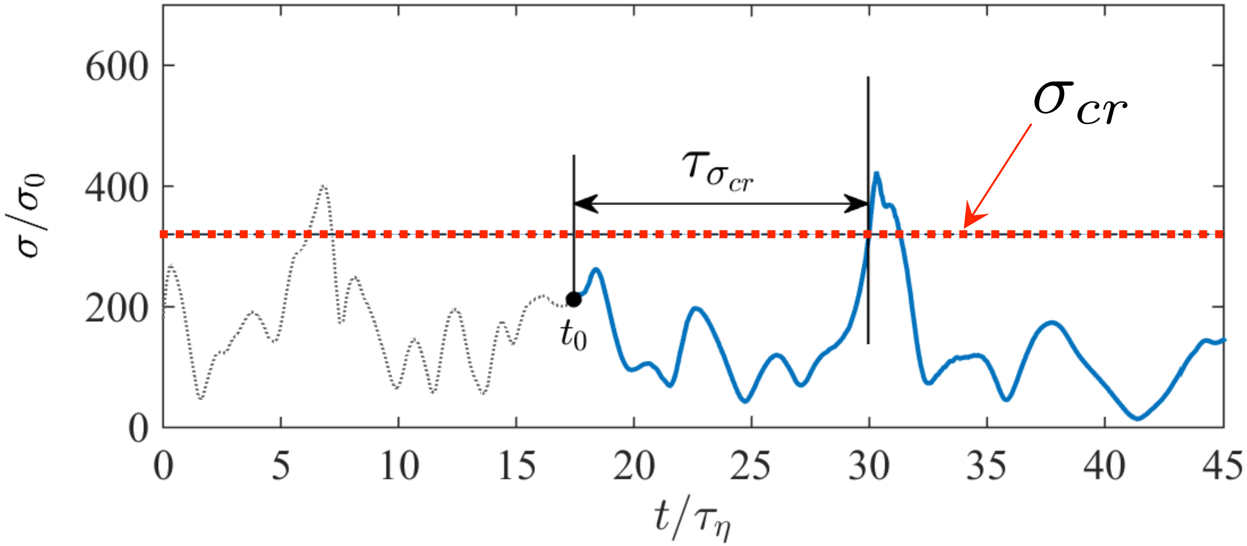
Numerical framework

- Upon release, we follow the aggregate until the first crossing of σ_{cr}

- Breakup rate:

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





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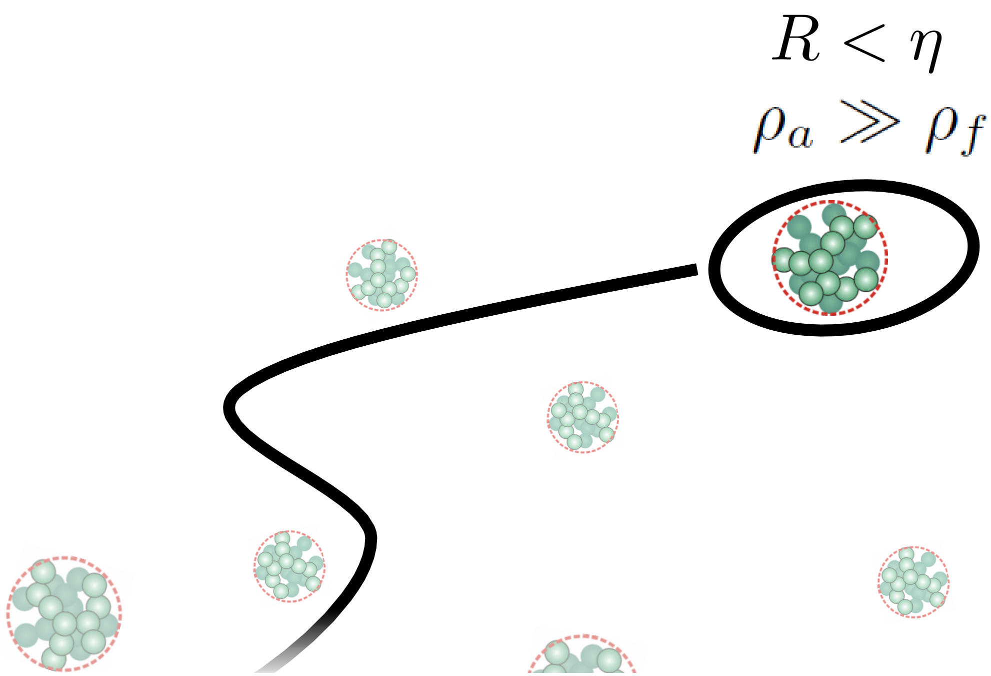
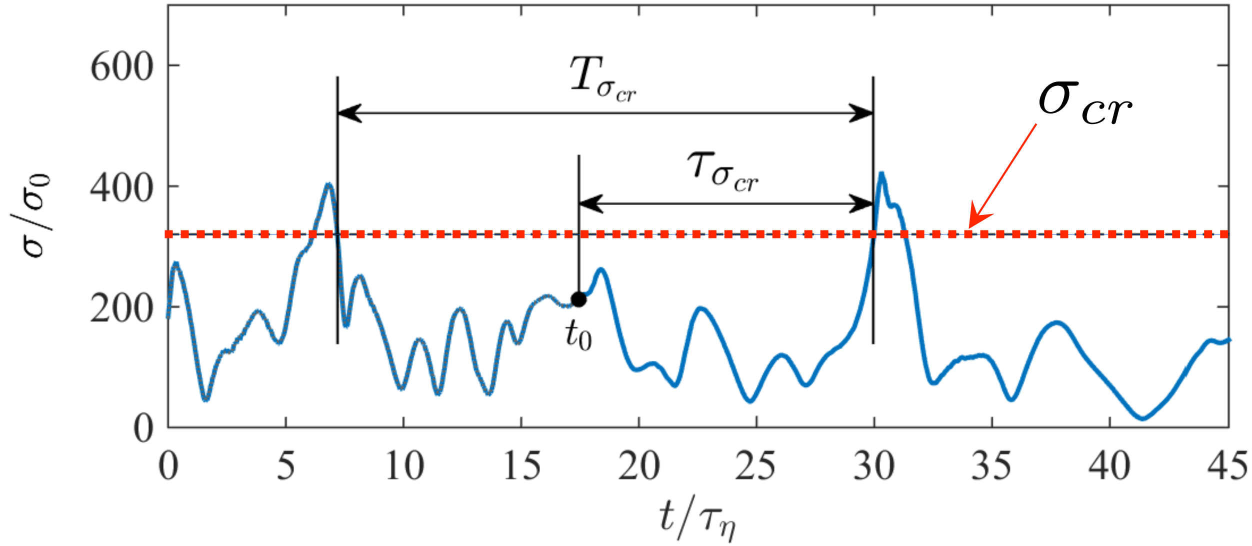


- Breakup rate:

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

- Quasi-Eulerian proxy:

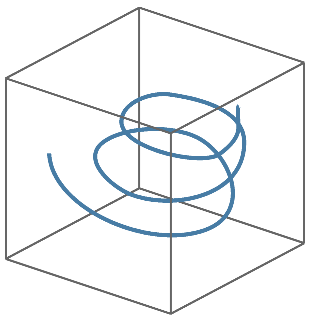
$$f^{(E)}_{\sigma_{\rm cr}} = \frac{1}{\langle T_{\sigma_{\rm cr}} \rangle} = \frac{\int_0^\infty d\dot{\sigma}\, \dot{\sigma} p_2(\sigma_{\rm cr}, \dot{\sigma})}{\int_0^{\sigma_{\rm cr}} d\sigma\, p(\sigma)}$$



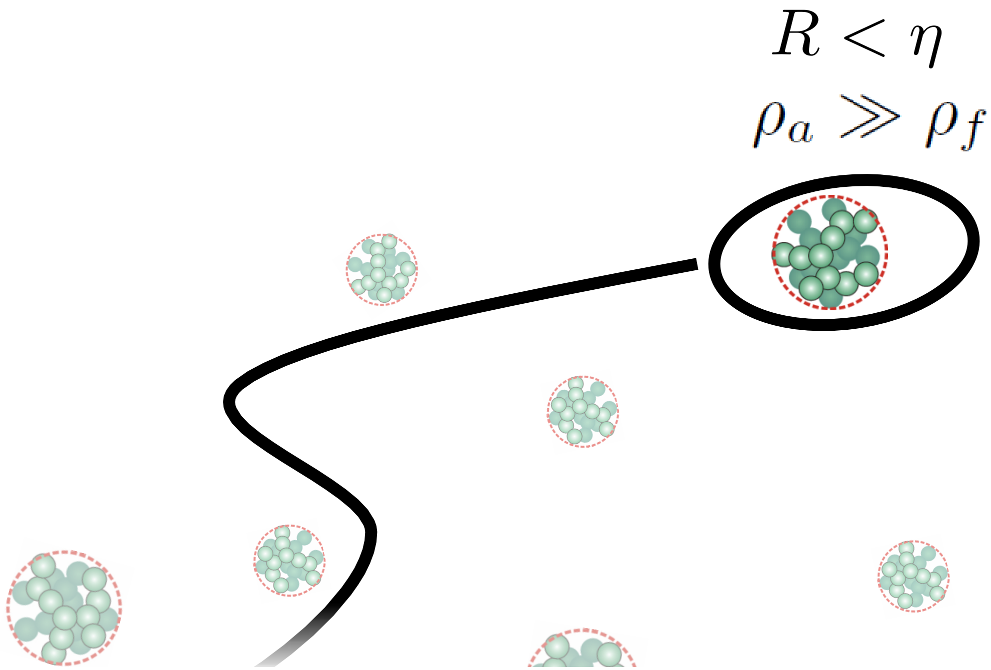
Babler, Biferale, Lanotte, *PRE* (2012)

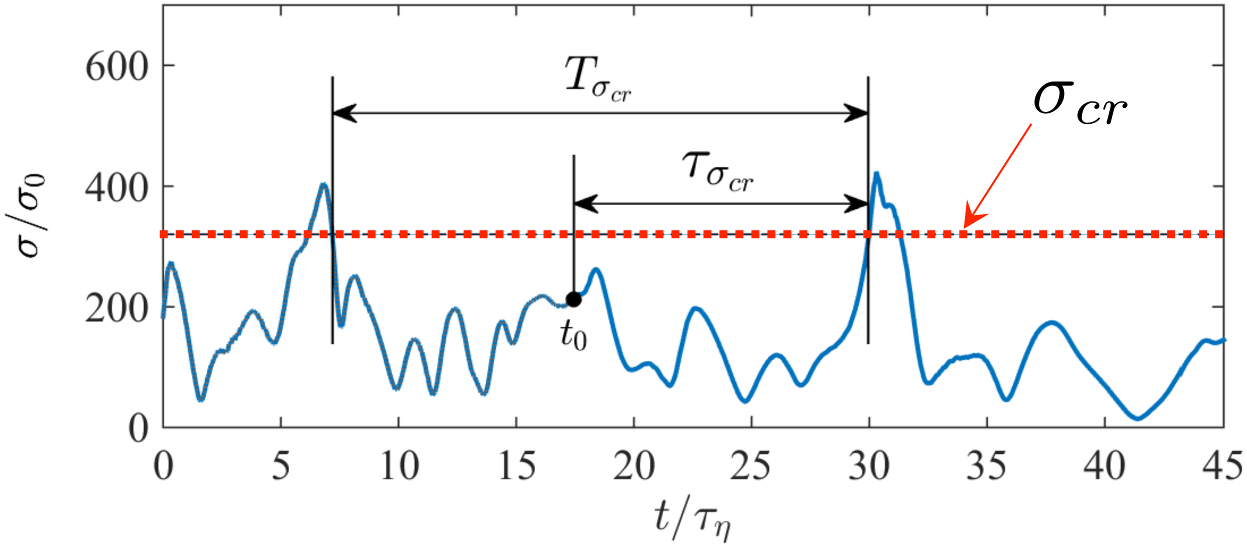
Numerical framework

- Turbulent trajectories for HIT are available:



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

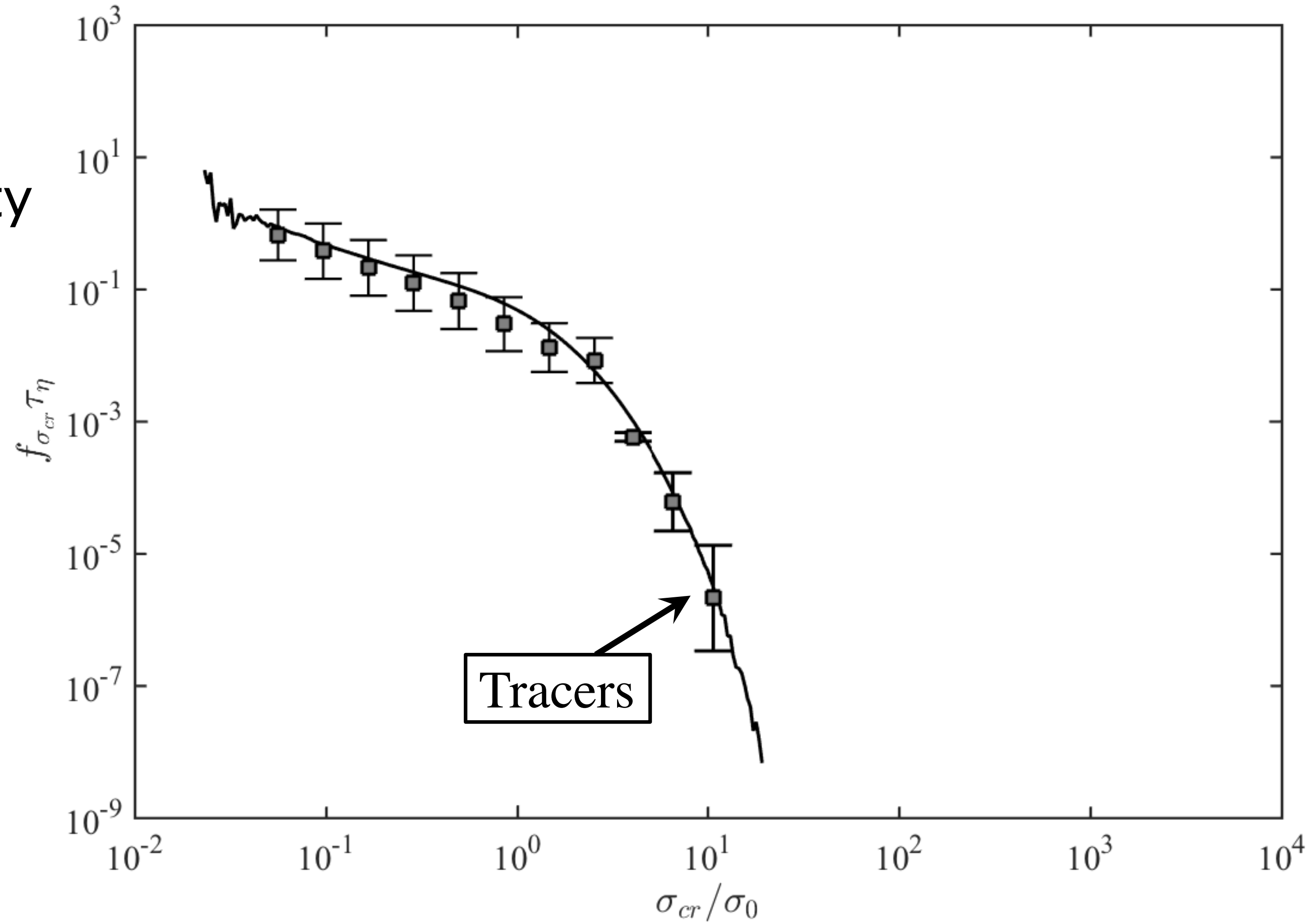




Bec, Biferale, Lanotte, Scagliarini, Toschi, *JFM* (2010)

Breakup rate

- Aggregates of size $R/\eta = 0.1$ and varying density



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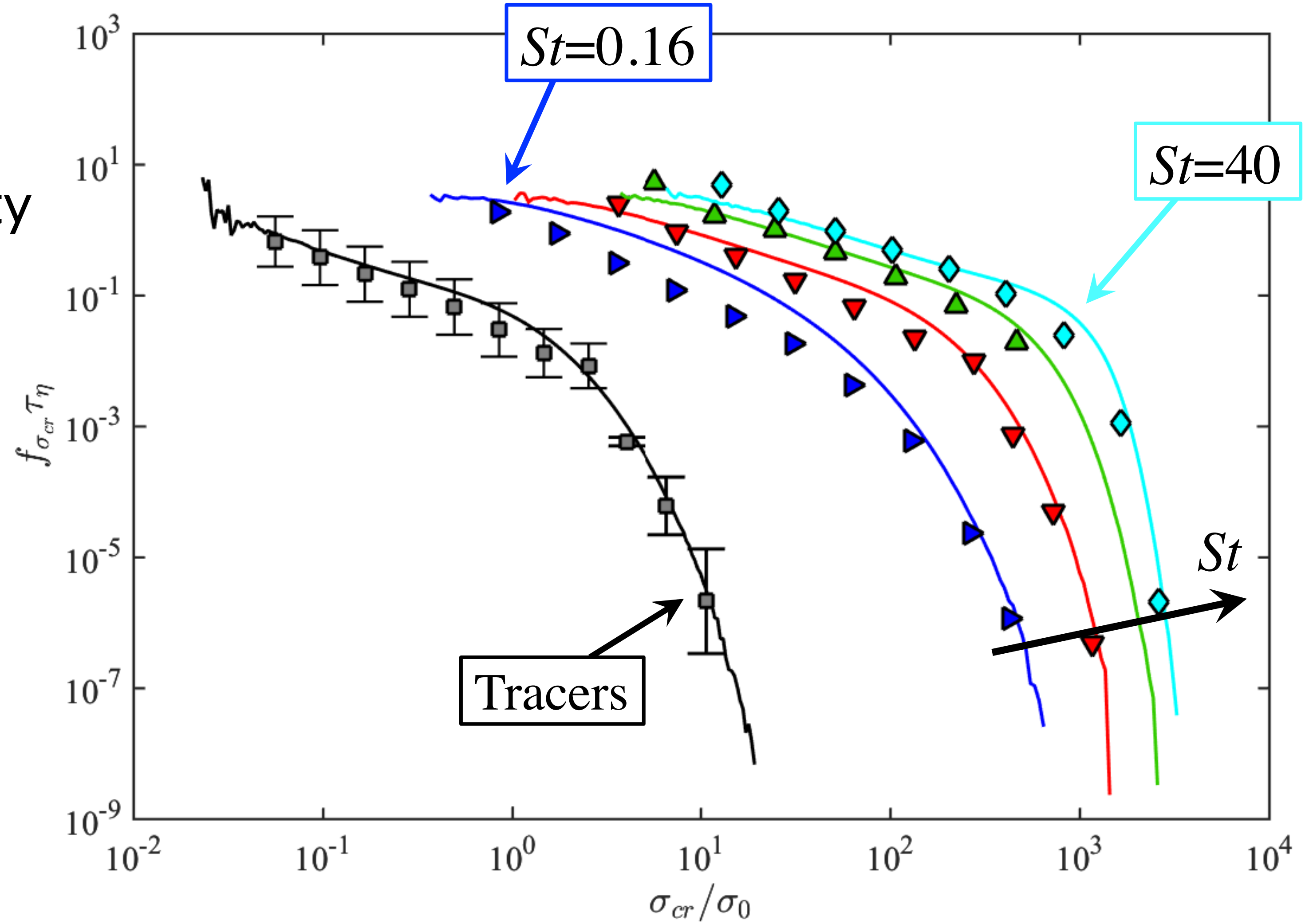


Breakup rate

- Aggregates of size $R/\eta = 0.1$ and varying density

- Small σ_{cr}

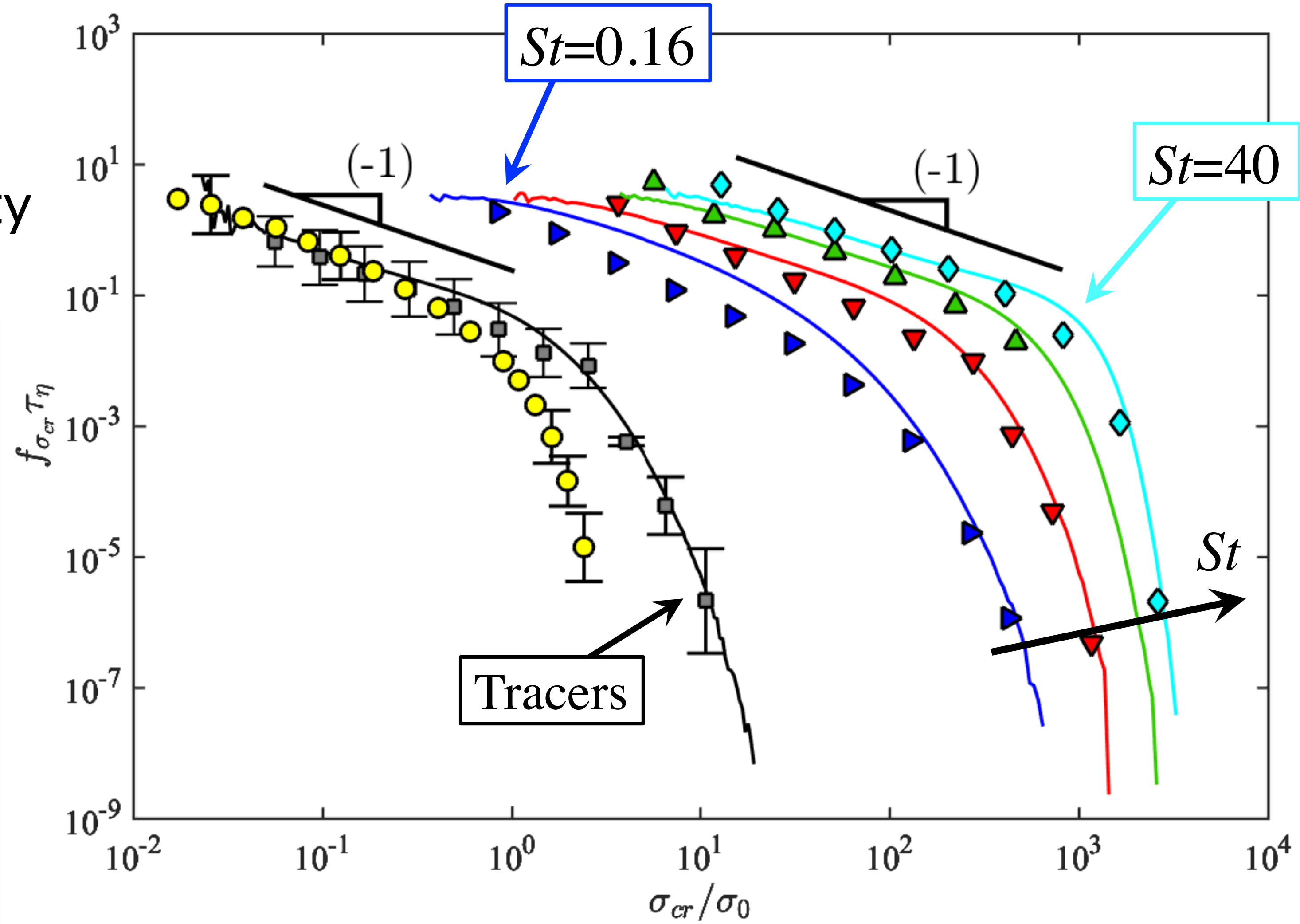
$$f^{(E)}_{\sigma_{\rm cr}} = \frac{\int_0^\infty d\dot\sigma\, \dot\sigma p_2(\sigma_{\rm cr}, \dot\sigma)}{\int_0^{\sigma_{\rm cr}} d\sigma\, p(\sigma)}$$

- Closure

$$p_2(\sigma, \dot\sigma) = p(\sigma)p(\dot\sigma)$$

$$p(\sigma) \sim \text{Gaussian}$$

$$\Rightarrow \quad f_{\sigma_{\rm cr}} \sim \sigma_{\rm cr}^{-1}$$



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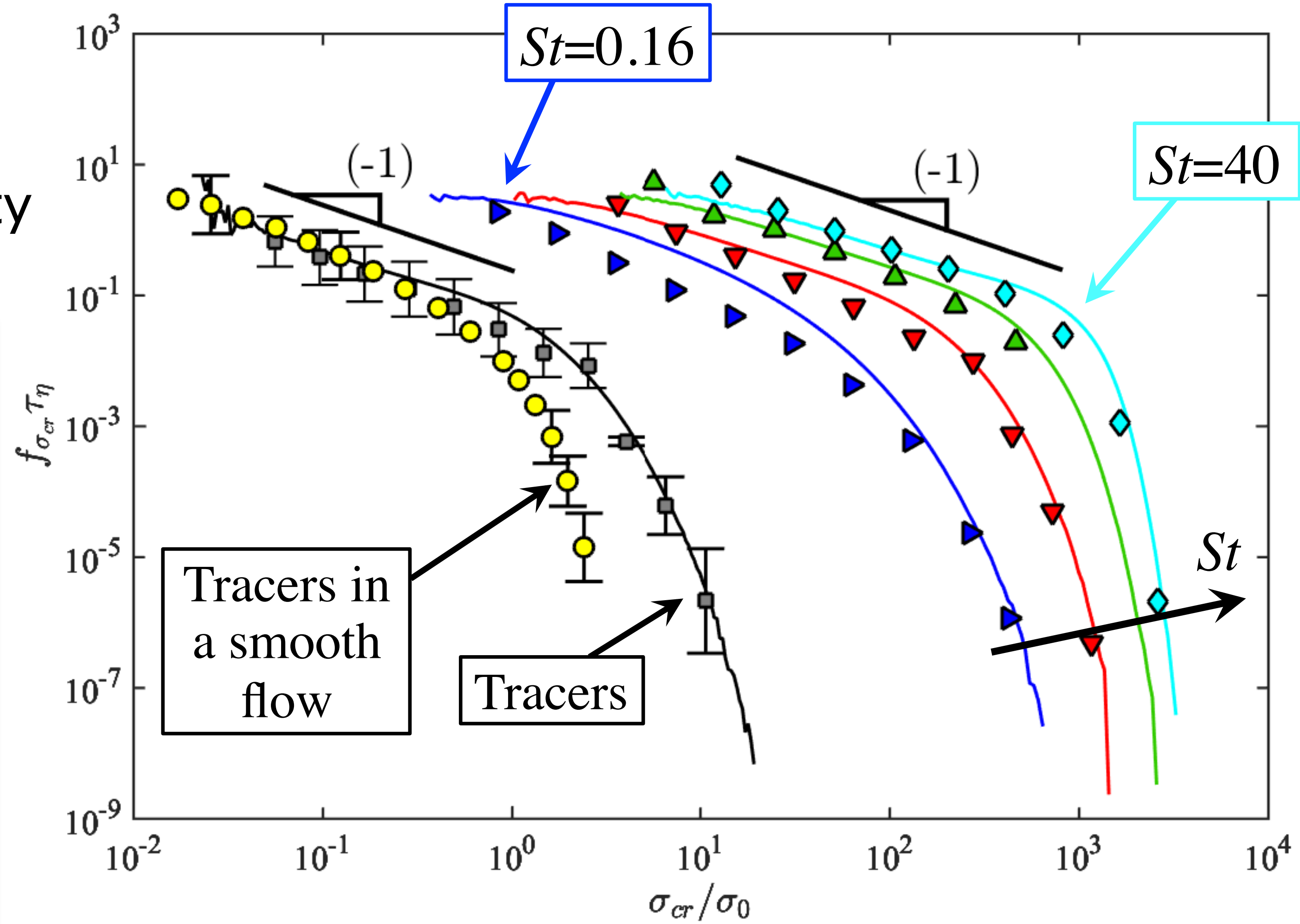

Conclusions

The breakup of inertial aggregates due hydrodynamic stress, caused by shear and drag, in homogeneous turbulence was investigated.

- The aggregate breakup rate as a function of the critical stress at a given Stokes number shows a slow power-law like decay at small stress, followed by a sharp cut-off of high stress.
- As Stokes is increased the drag stress becomes dominant and less intermittent, resulting in a more abrupt cut-off.
- The power-law behavior is controlled by Gaussian fluctuations, as evidenced from measuring the breakup rate in a synthetic flow with Gaussian statistics.

Acknowledgments

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