A Lagrangian model of Copepod dynamics: clustering by escape jumps in turbulence

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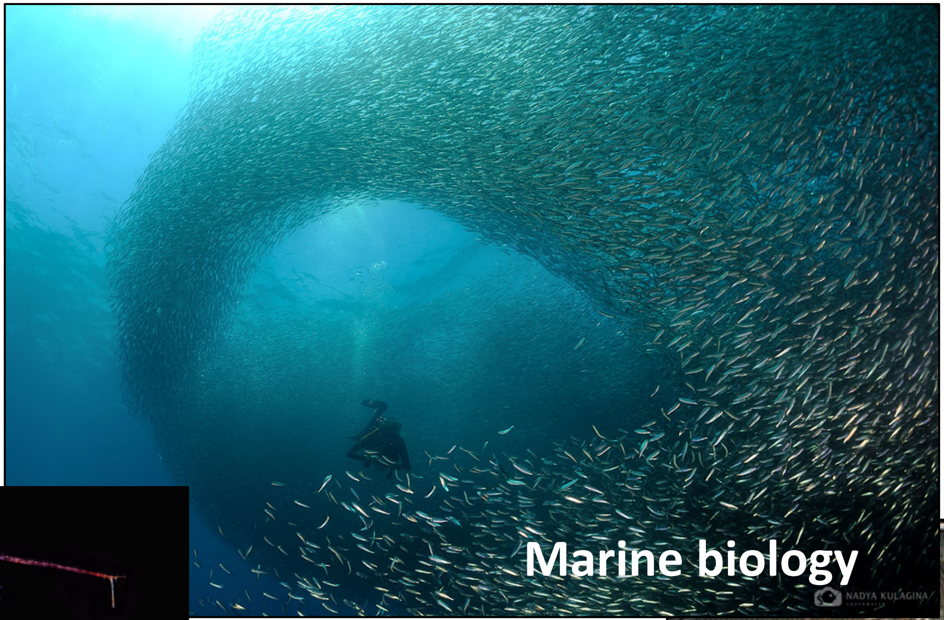
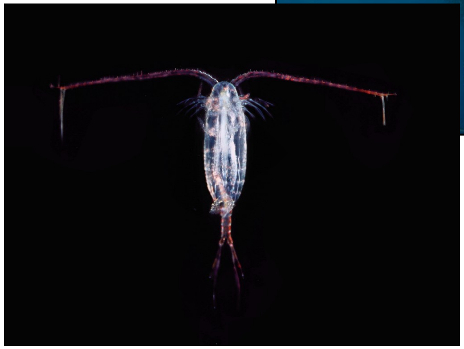
Outline

- Motivation
- Introduction to Copepods
- Experimental Data Analysis
- Lagrangian Copepod Model
- Analysis
- Conclusion & Perspective

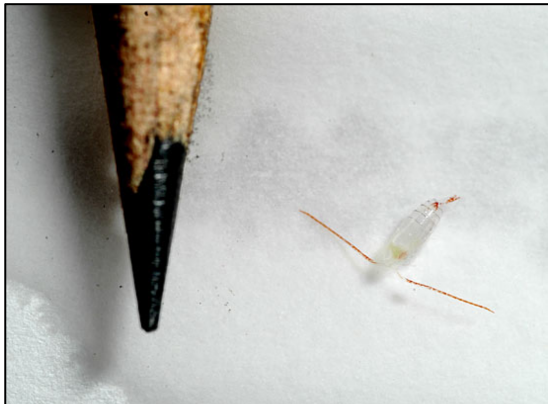
Motivation

- Important link in the food web
- Most numerous crustaceans in the ocean
- Fishery Industry
- Better understanding the oceanic life

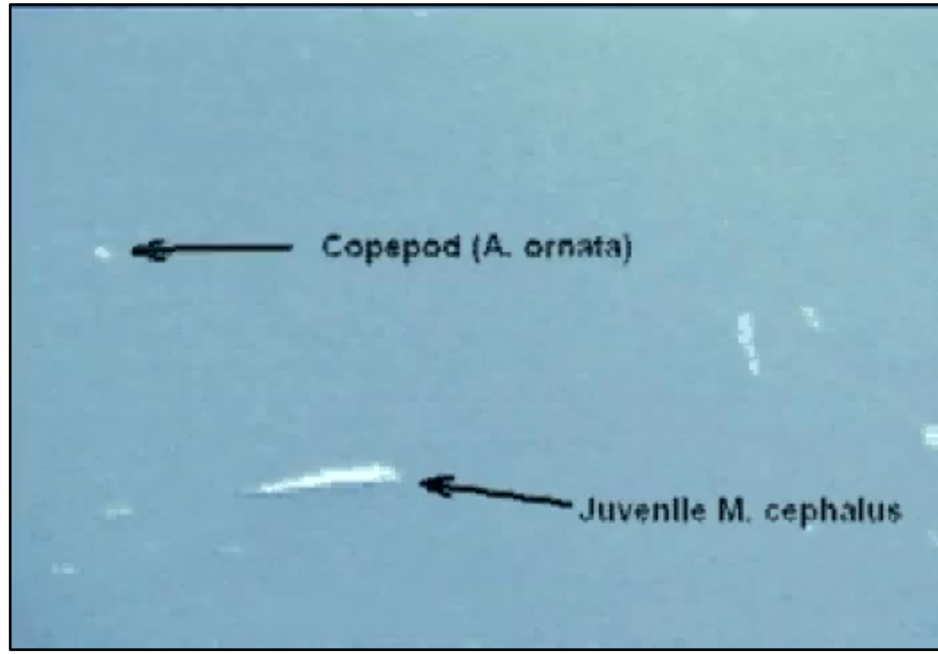


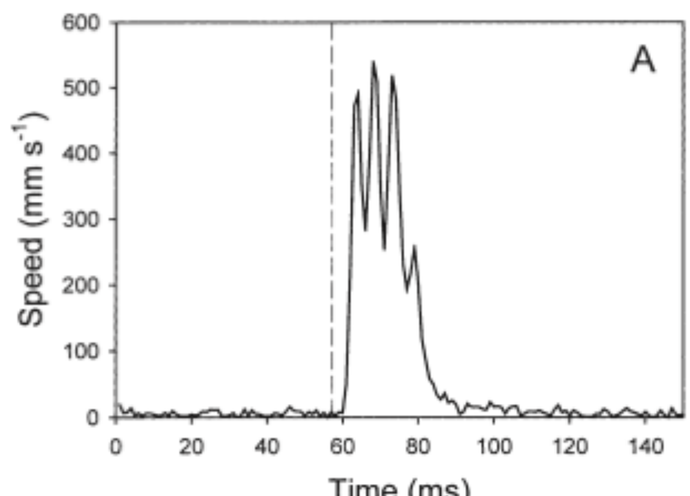


What Are Copepods?



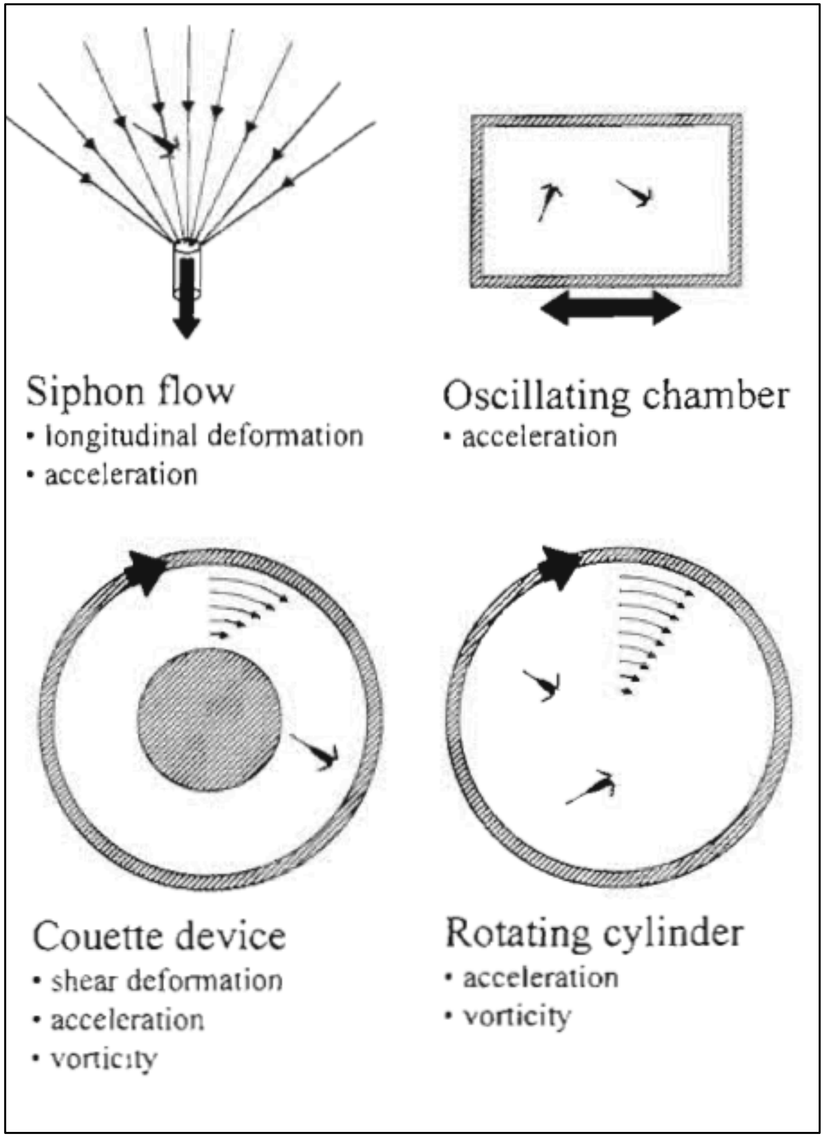
Copepods cultures at LOG Lab in Wimereux





Buskey et all., (2002)

Component of The Flow?



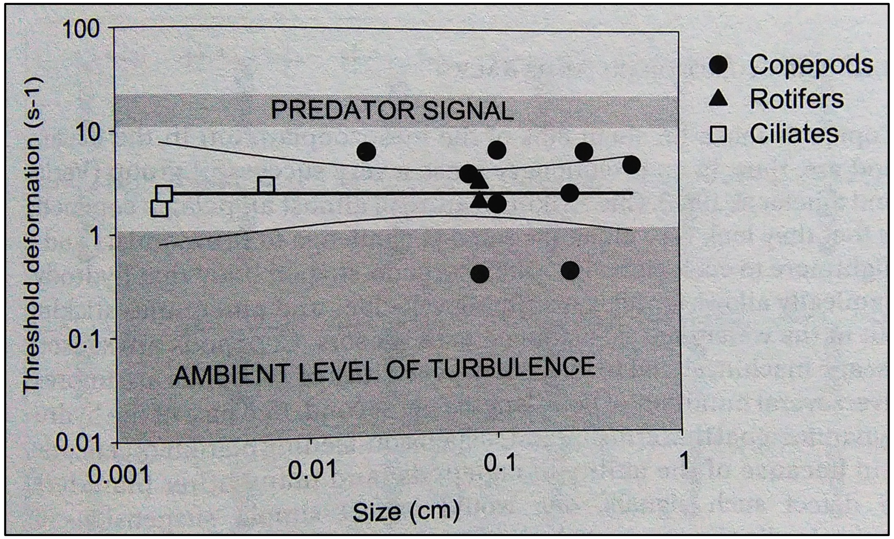
Kiørboe et all., (1999)

Acceleration?

Deformation rate?

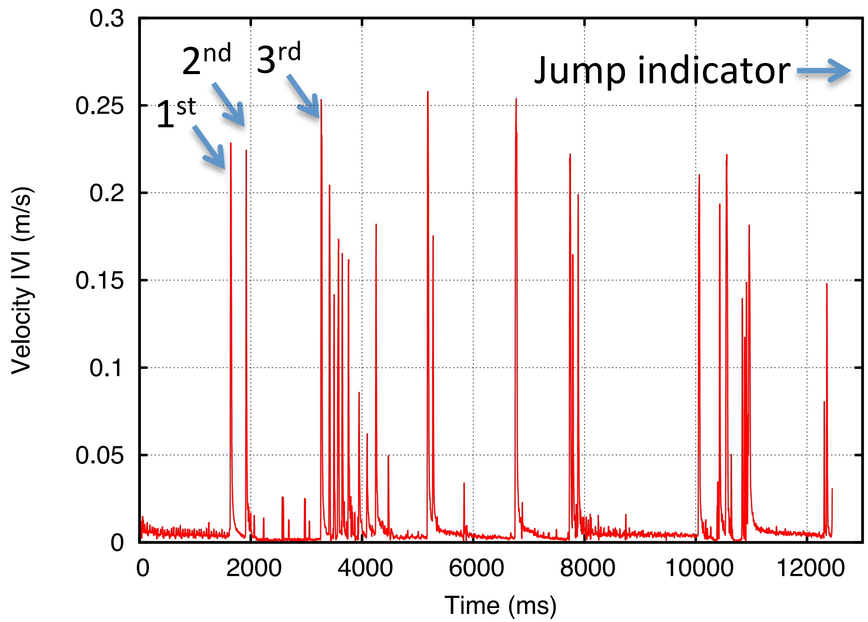
Vorticity?

Copepods react to deformation rate



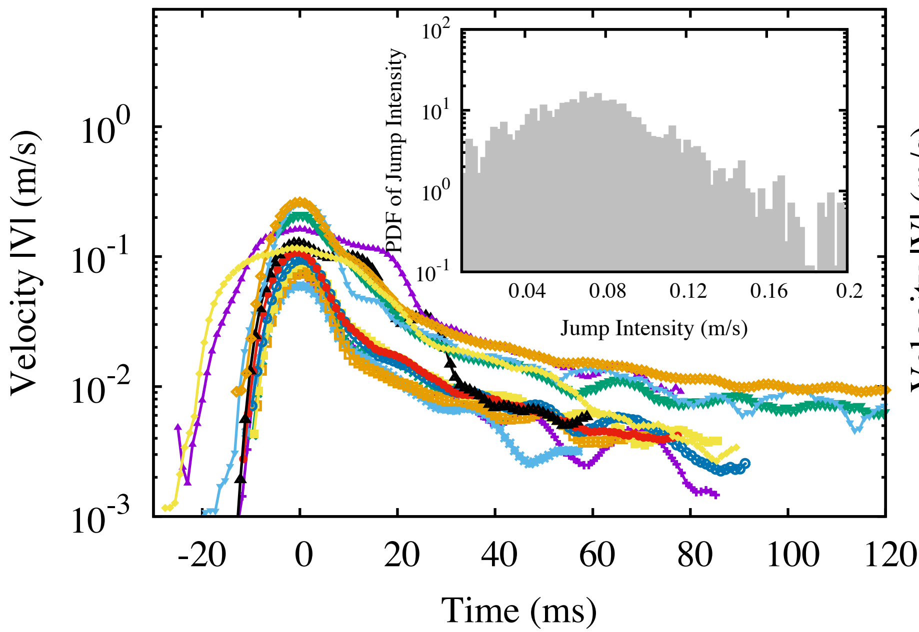
Kiørboe, A Mechanistic Approach to Plankton Ecology, (2008)

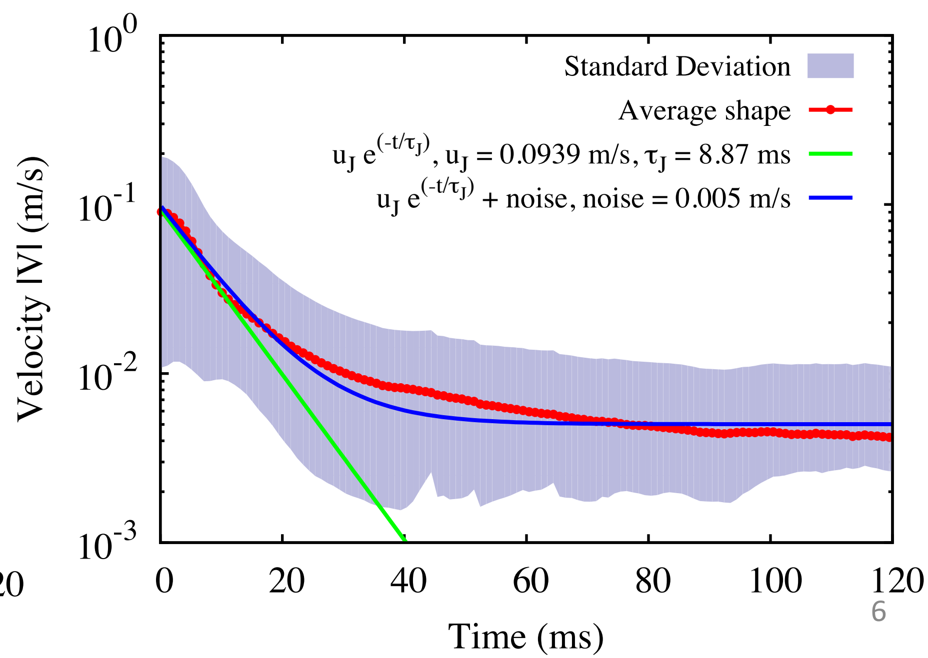
Experimental Jump Data Analysis



Response of copepod (Eurytemora affinis) to light stimuli in still water, Data collected by **Ibtissem Benkeddad** at LOG, Wimereux

Jumps superposed by considering their peak as a reference.





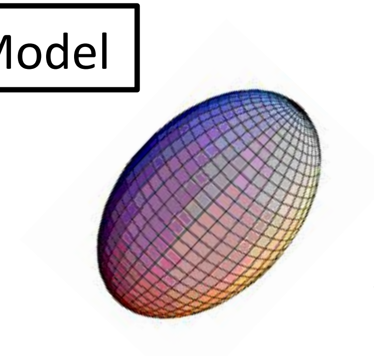
Lagrangian Copepod (LC) Model in a Flow

Model assumptions:

- Copepods as rigid, homogeneous, neutrally buoyant particle
- Same way of response to external flow disturbances
- A mechanical signal with a single-threshold
- Drag force (no gravity)

Modified Chlamydomonas Model

$$\dot{\mathbf{x}}(t) = \mathbf{u}(\mathbf{x}(t), t) + \boldsymbol{J}(t, t_i, t_e, \dot{\gamma}, \mathbf{p})$$



$\alpha \equiv l/d$

Shape effect

Parameter	Unit	Range		This study
ν	$m^2 s^{-1}$	$\sim 10^{-6}$		10^{-6}
ϵ	$m^2 s^{-3}$	10^{-8}	10^{-4}	10^{-6}
η	m	3×10^{-3}	3×10^{-4}	10^{-3}
τ_η	s	10	0.1	1
u_η	ms^{-1}	3×10^{-4}	3×10^{-3}	10^{-3}
Re_λ	–	$\mathcal{O}(10^2)$		80

Properties of the ocean water

Dimensionless control parameters

u_J/u_η $\qquad$ τ_J/τ_η $\qquad$ $\tau_\eta \dot{\gamma}_T$

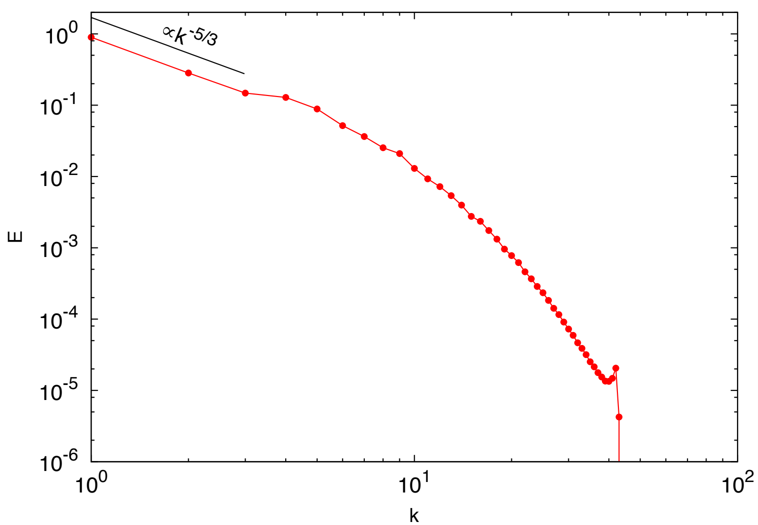
Numerical Method

Eulerian - Lagrangian

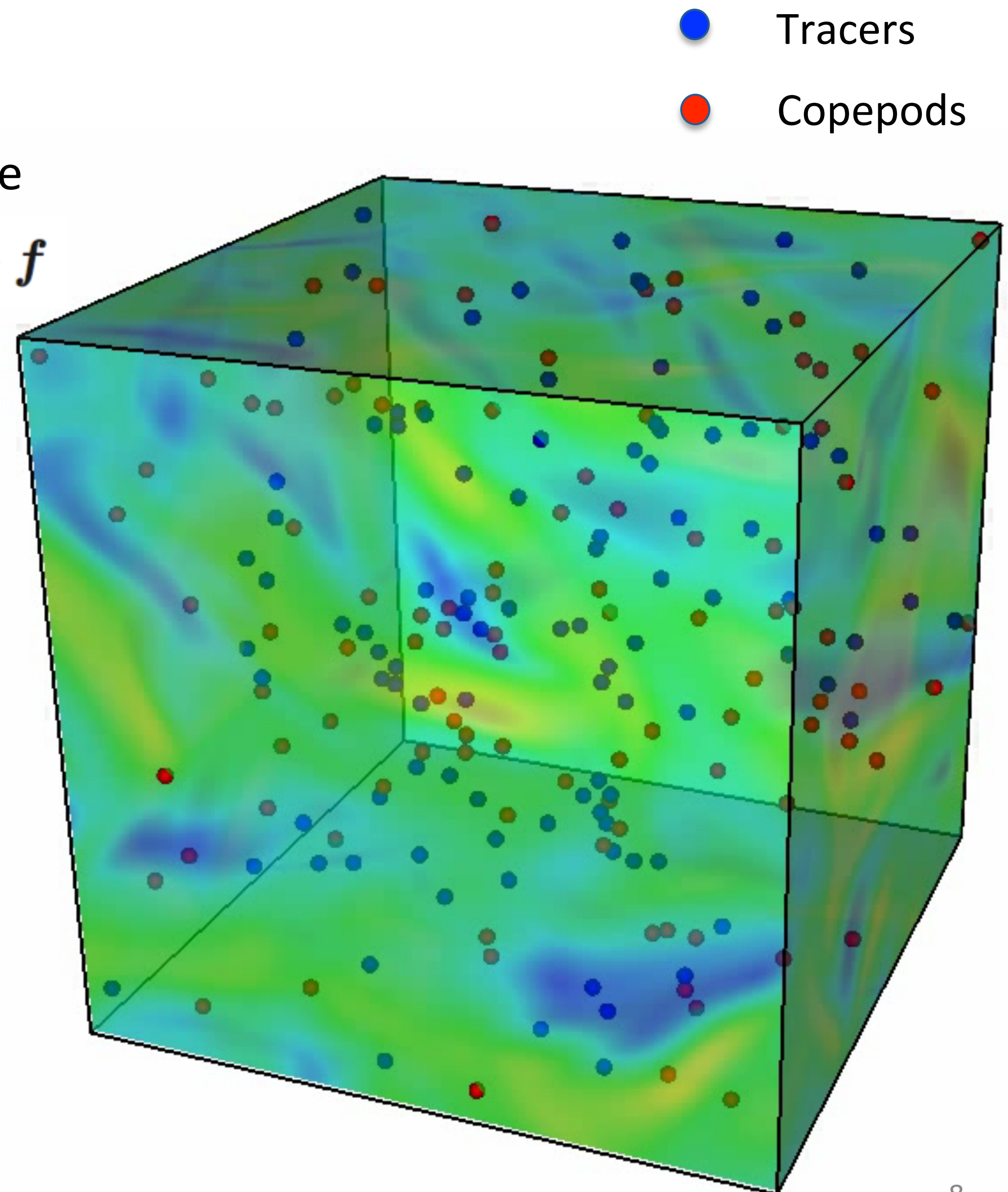
Homogeneous Isotropic Turbulence

$$\partial_t \mathbf{u} + \mathbf{u} \cdot \nabla \mathbf{u} = -\nabla p/\rho + \nu \Delta \mathbf{u} + \boldsymbol{f}$$

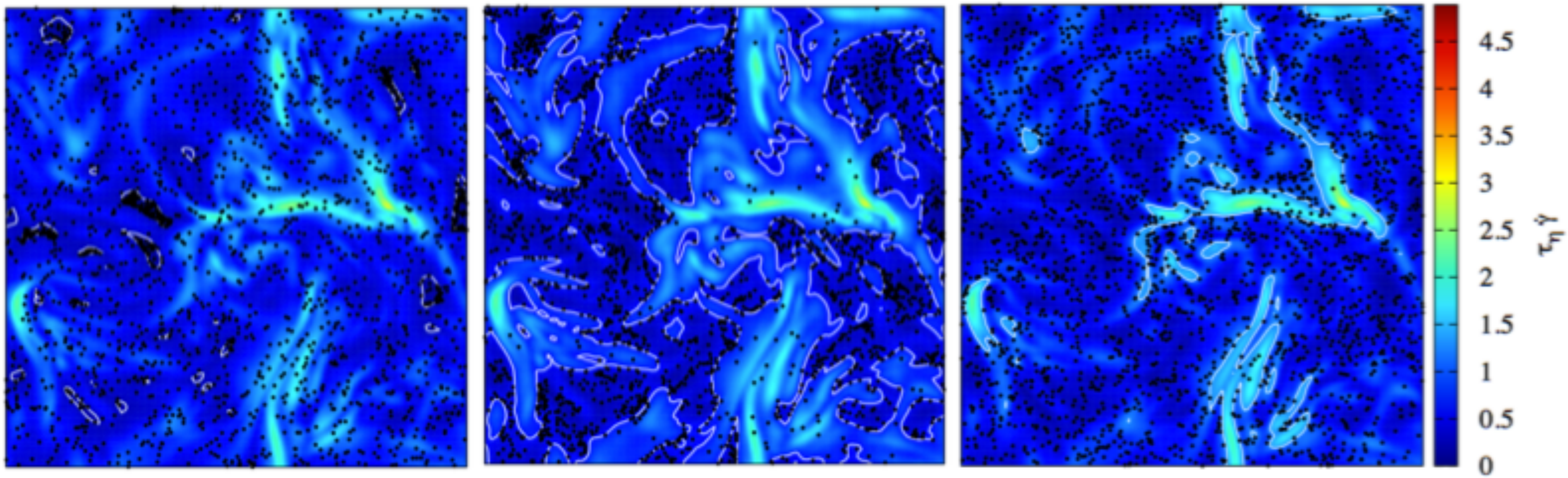
$$\nabla \cdot \mathbf{u} = 0$$



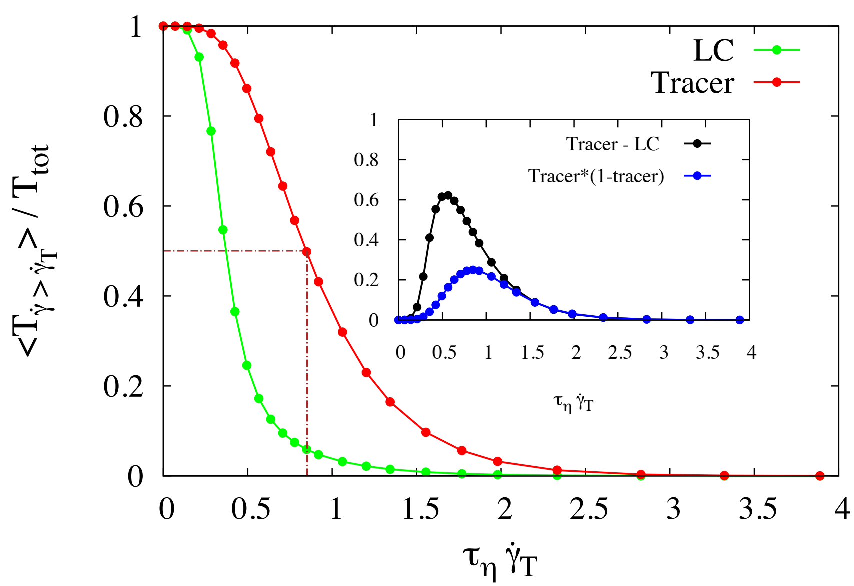
Spectral Method



Clustering



$\tau_\eta \dot{\gamma}_T = 0.35$ $\tau_\eta \dot{\gamma}_T = 0.92$ $\tau_\eta \dot{\gamma}_T = 1.77$



Jump intensity $u_J/u_\eta = 250$

Alert region : $\dot{\gamma} > \dot{\gamma}_T$

Comfort region : $\dot{\gamma} < \dot{\gamma}_T$

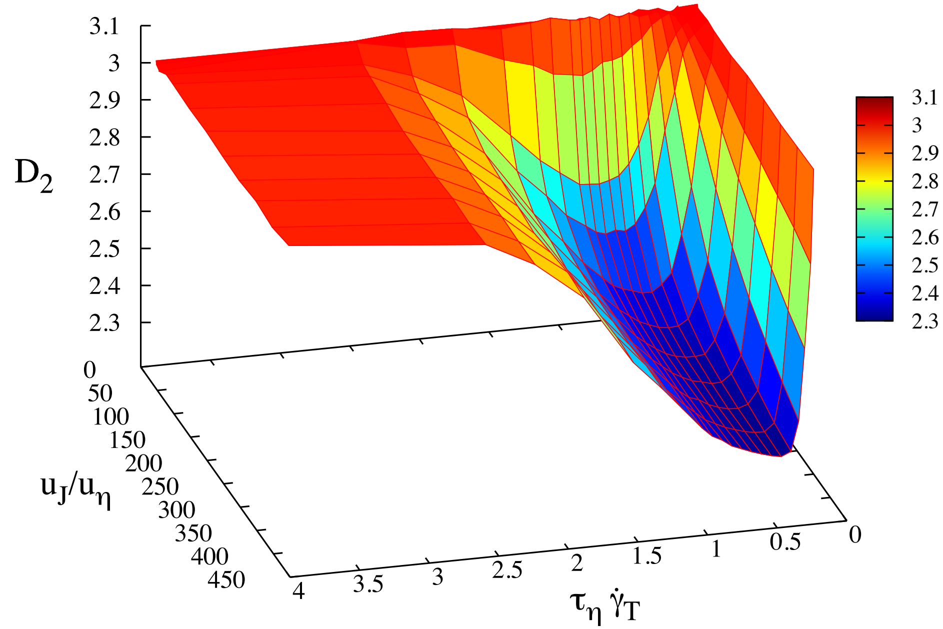
$$\langle T_{\dot{\gamma}>\dot{\gamma}} \rangle = \frac{1}{N_{tot}} \sum_{i=1}^{N_{tot}} \int_0^{T_{tot}} H\left(\dot{\gamma}_i(t) - \dot{\gamma}_T\right) dt$$

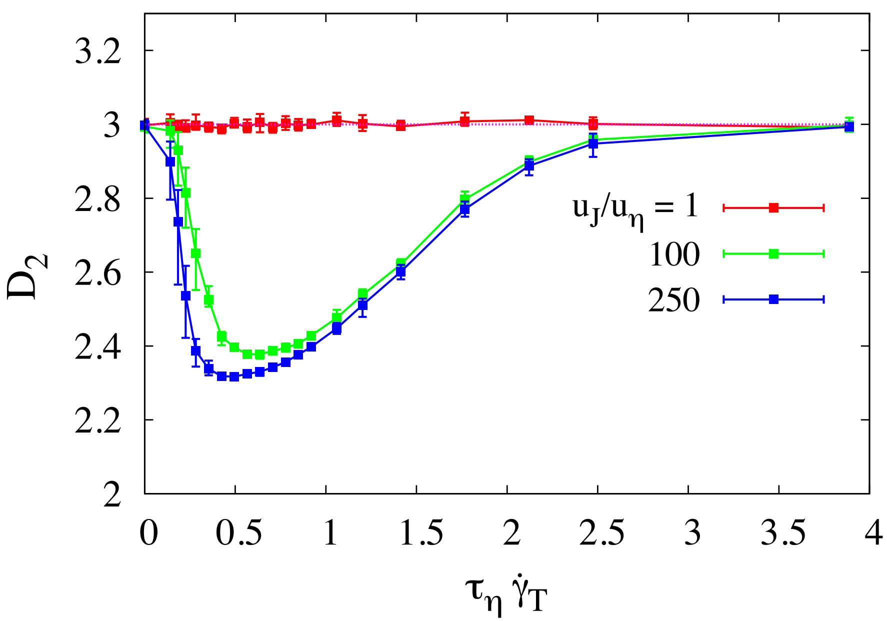
Correlation Dimension

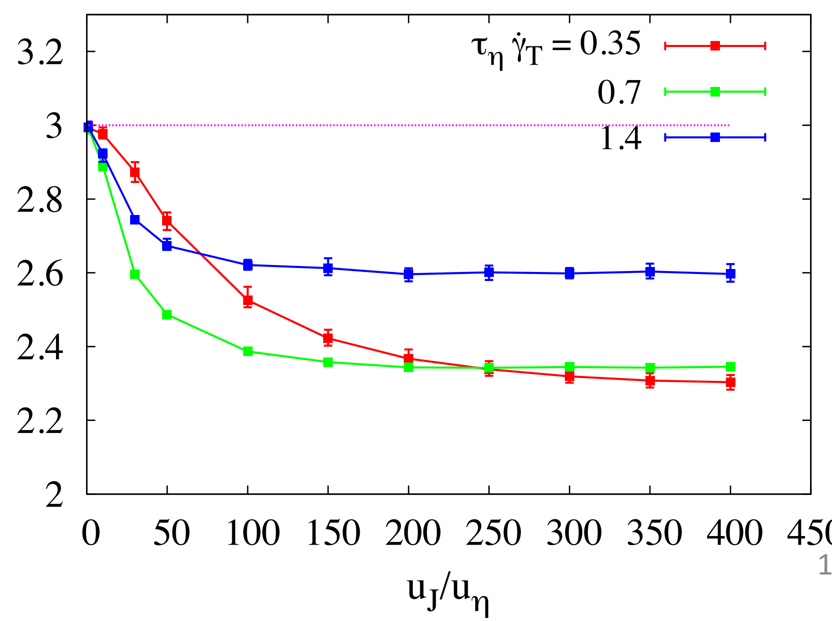
The **Grassberger-Procaccia** Algorithm:

$$C(r) = \frac{2}{N(N-1)} \sum_{i<j} H(r - |X_i - X_j|)$$

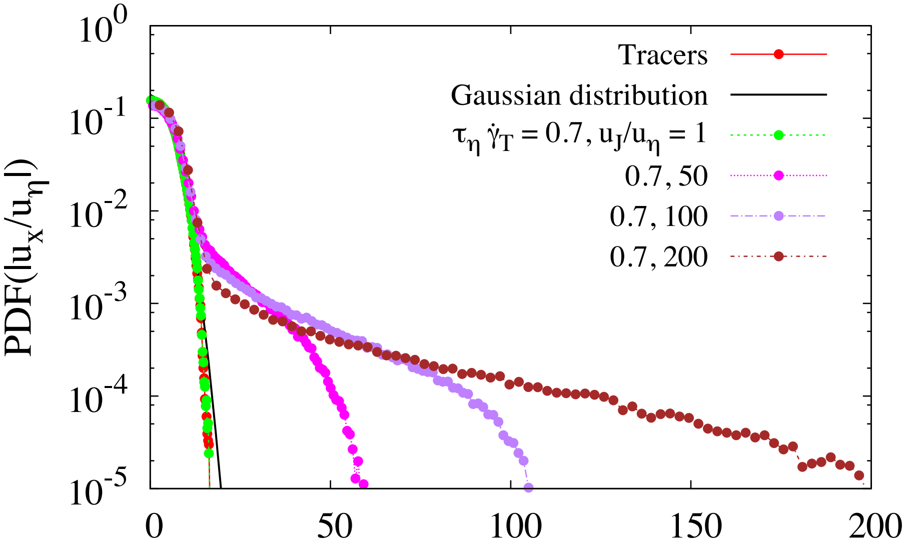
$$D_2 = \lim_{r \to 0} \frac{\log C(r)}{\log r}$$



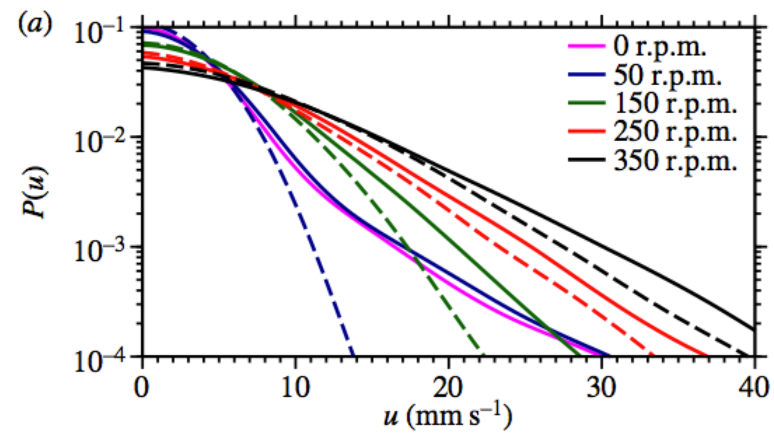


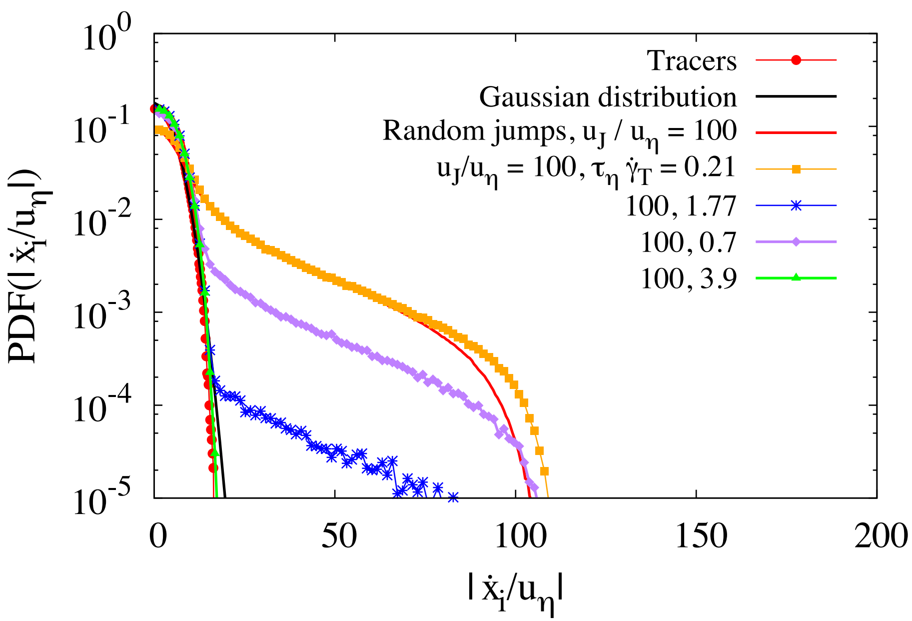


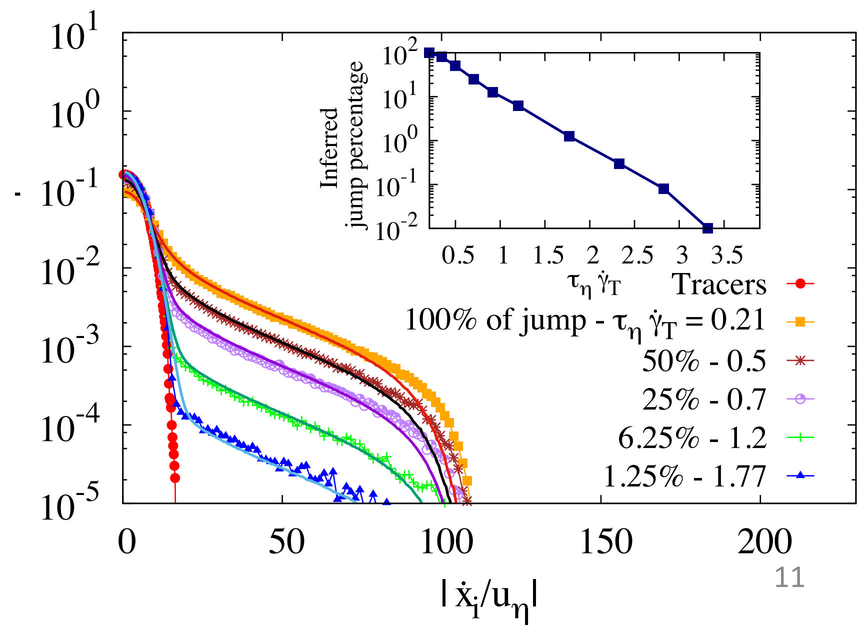
PDF of Velocity



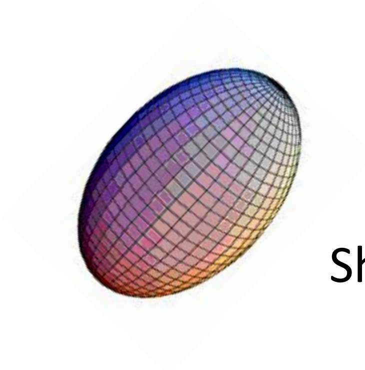
F. G. Michalec et al. (Journal of The Royal Society Interface (2015)).





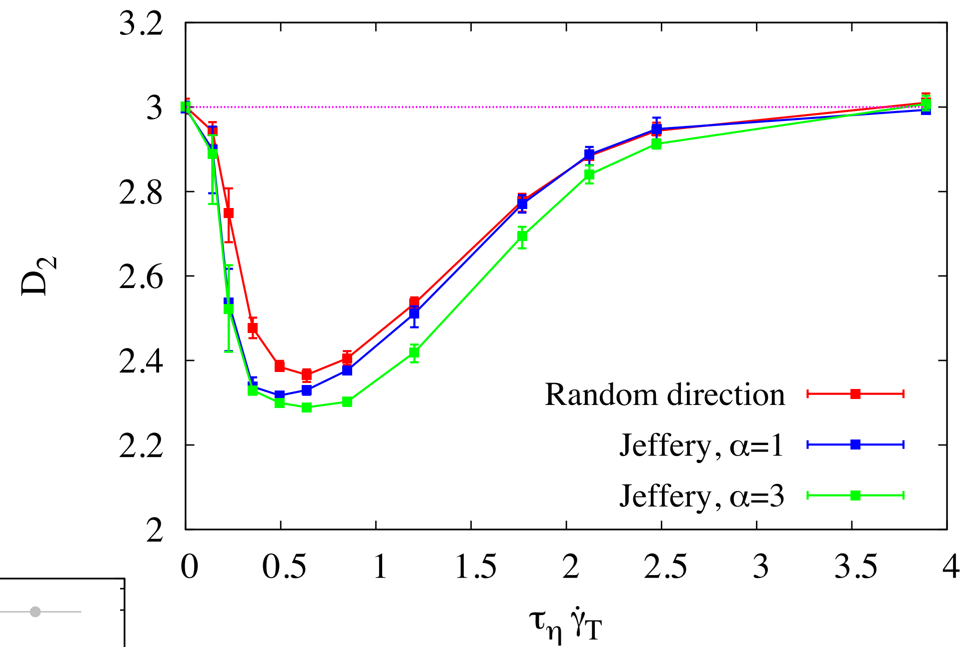


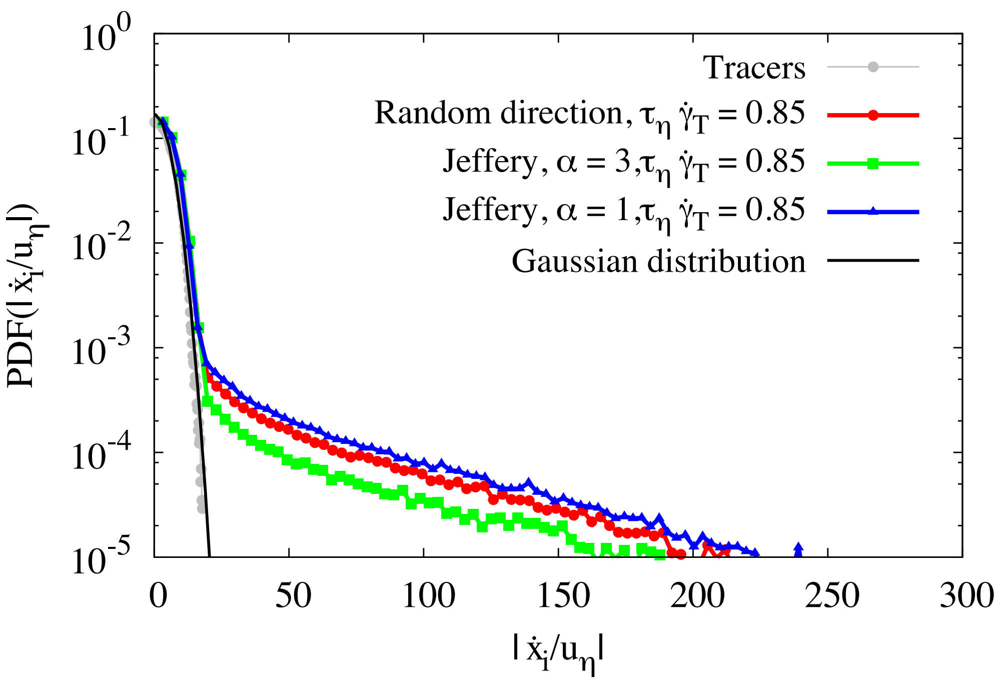
Particles Orientational Dynamics



$\alpha \equiv l/d$

Shape effect





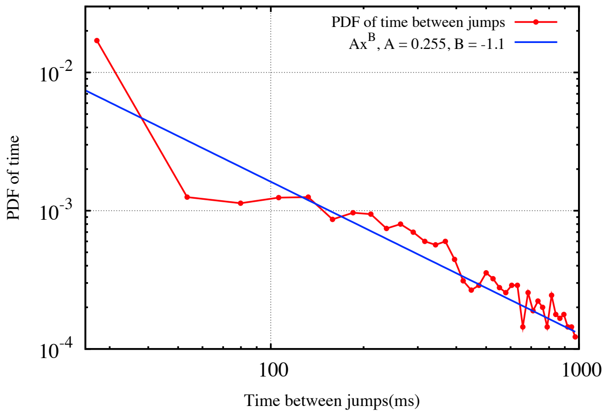
Conclusion & Perspective

Conclusion:

- The LC model leads to clustering different from the one observed for motile algae (*e.g.* De Lillo et al.(PRL 2014)).
- Particle orientational dynamics has negligible impact of on the clustering
- Clustering happens in narrow range

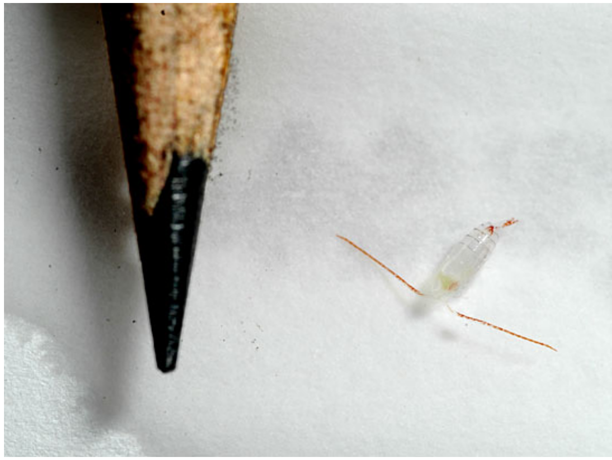
Perspective:

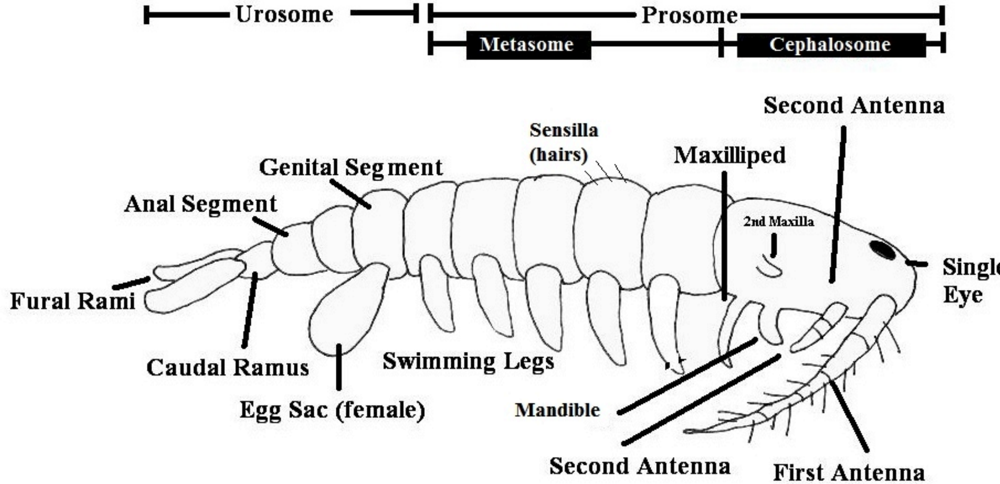
- Model refinement (taking into account the memory effect)
- Modeling complex behaviour of copepods (considering the radius of perception)
- Tune the model with experimental data

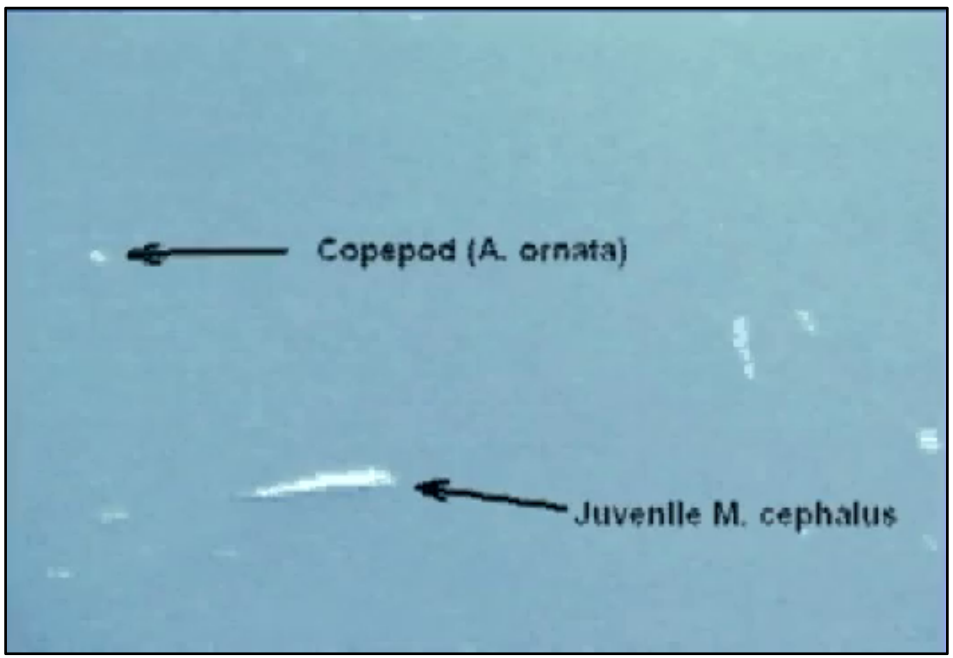


Thank you!

What are copepods?



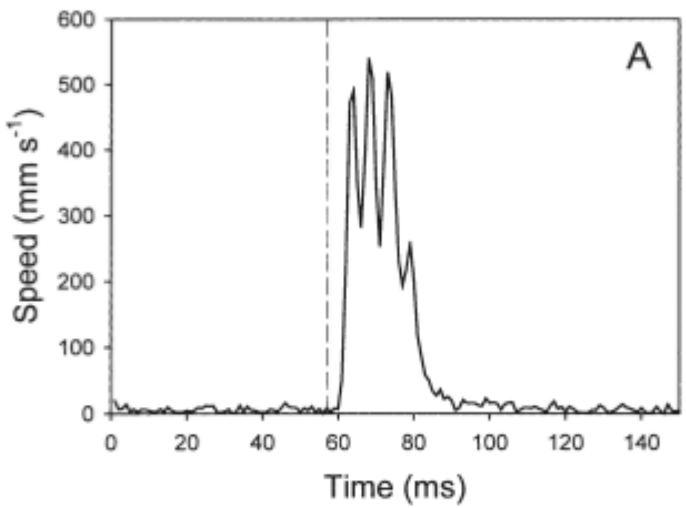




Copepods cultures at LOG Lab in Wimereux

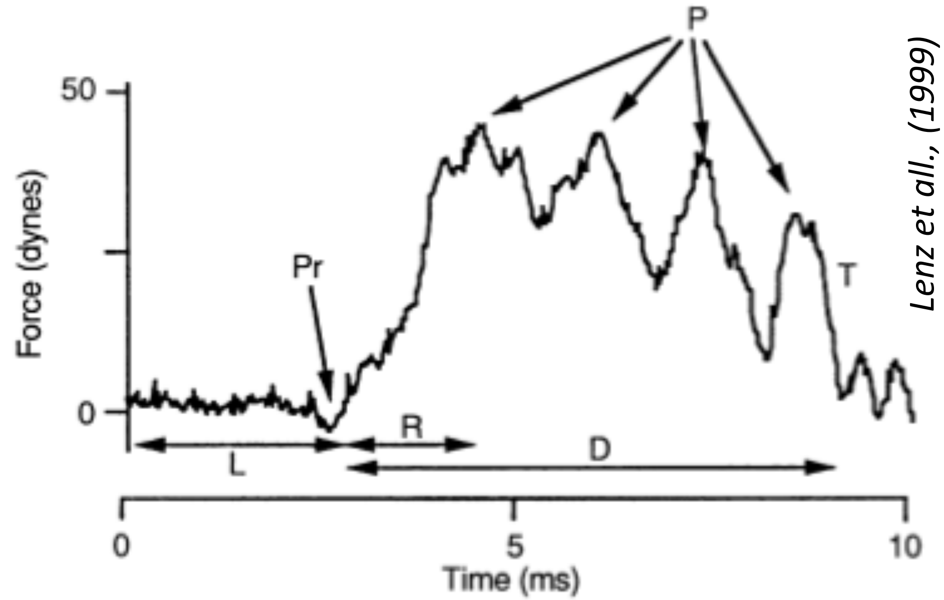
Response to Stimulus

Acartia tonsa: The stimulus occurred 3 (ms) before the initiation of the escape response (dashed line)



Buskey et all., (2002)

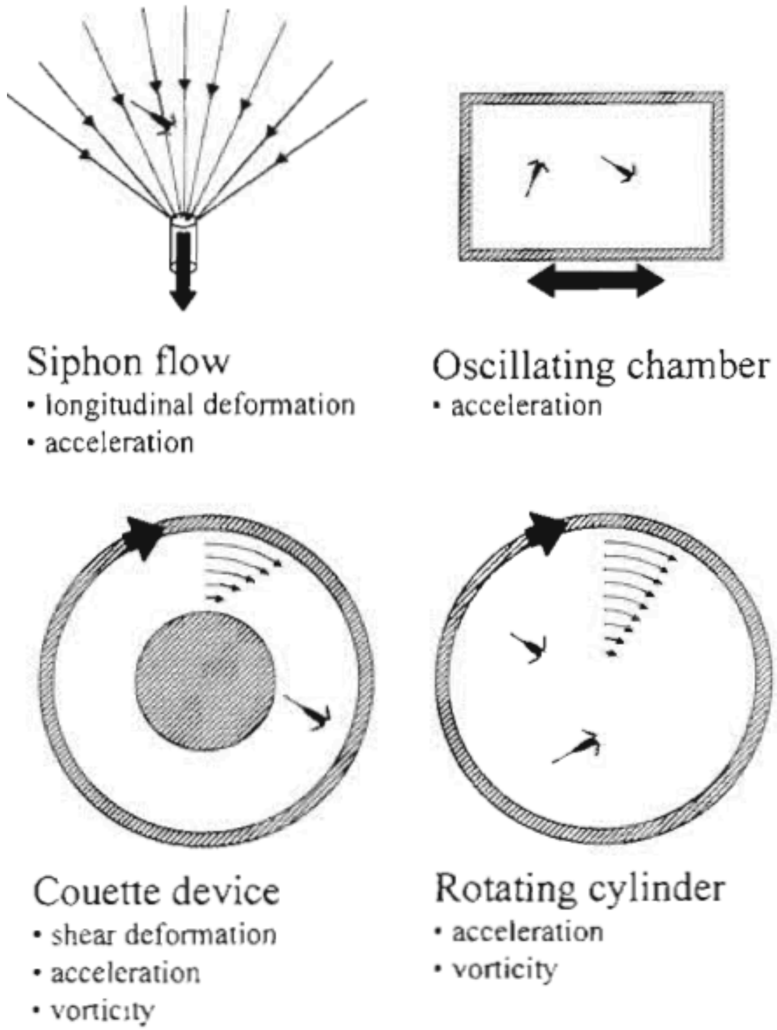
Response parameters



Lenz et all., (1999)

Undinula vulgaris giesbrechti response
L: latency to forward propulsion
Pr: preparation
R: rise
P: force peaks
D: kick (power strokes) duration
T: termination

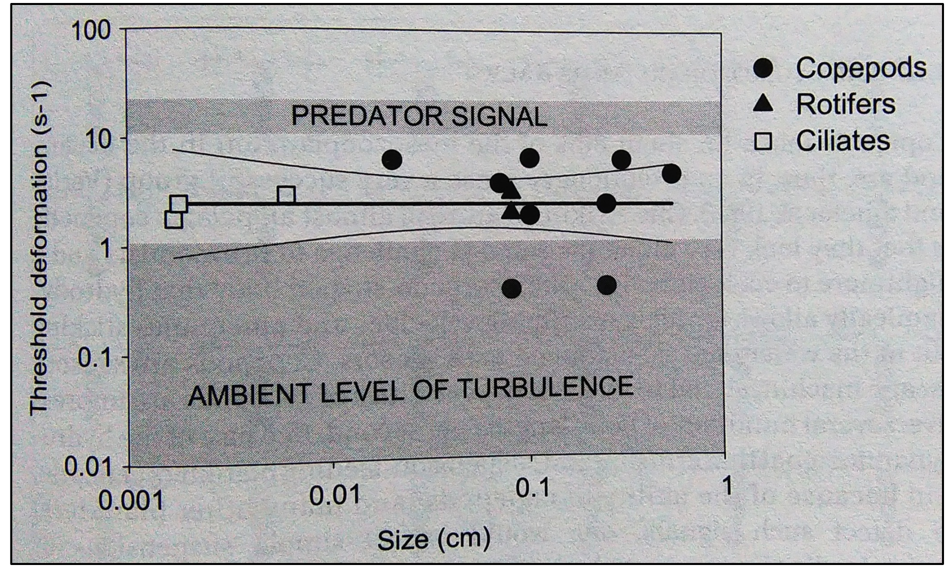
Component of the flow?



Kiørboe et all., (1999)

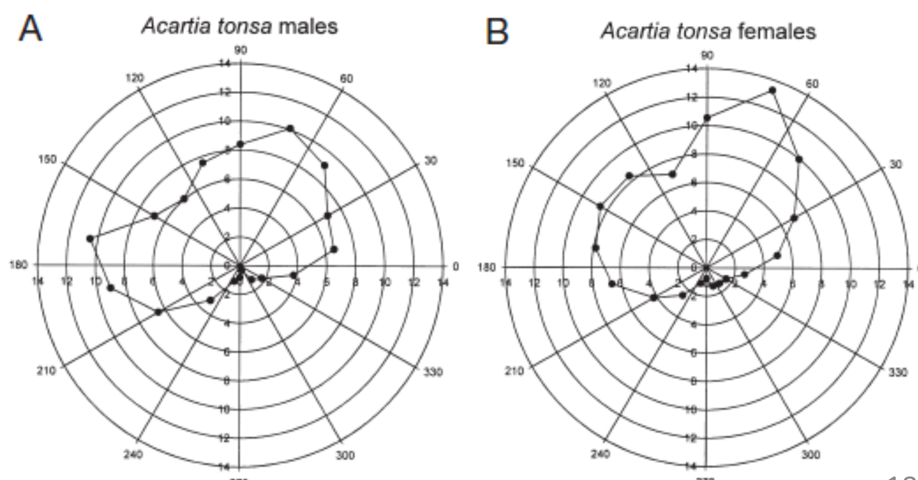
Copepods react to deformation rate

Thresholds



Kiørboe, A Mechanistic Approach to Plankton Ecology, (2008)

Direction of Escape?



Buskey et all., (2002)

Analysis

Quantifying spatial distribution of the copepods : Fractal dimension D_2

The **Grassberger-Procaccia** Algorithm:

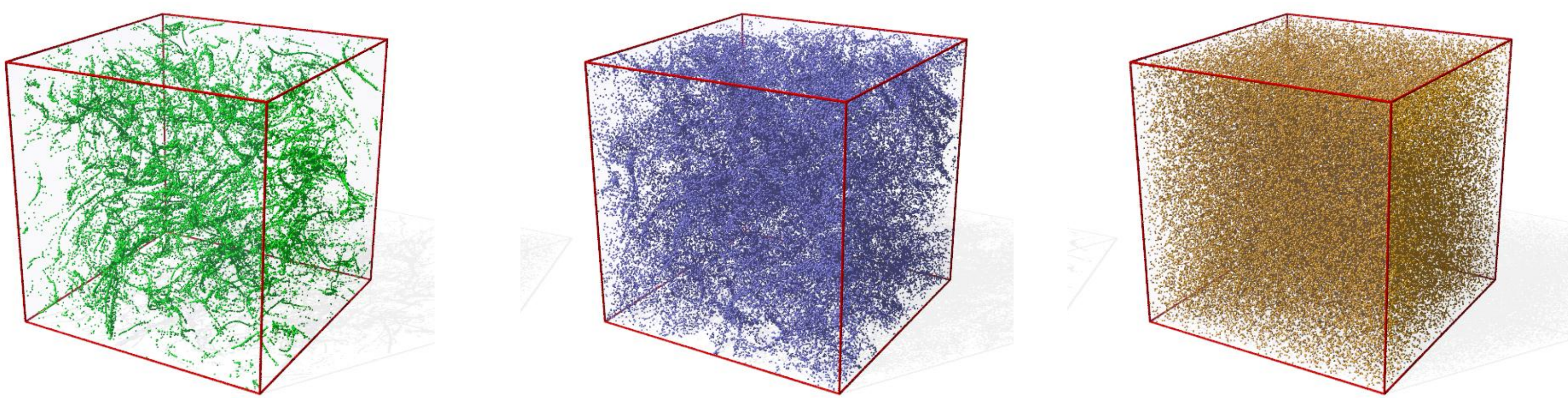
$$\hat{C}(r) = \frac{2}{N(N-1)} \sum_{i<j} \theta(r - |\mathbf{x}_i - \mathbf{x}_j|)$$

$\theta(x)$ is Heaviside step function

Monotonically decreasing like power law $C(r) \sim r^D$ as $r \to 0$

Probability to find a couple of particle whose distance is below r

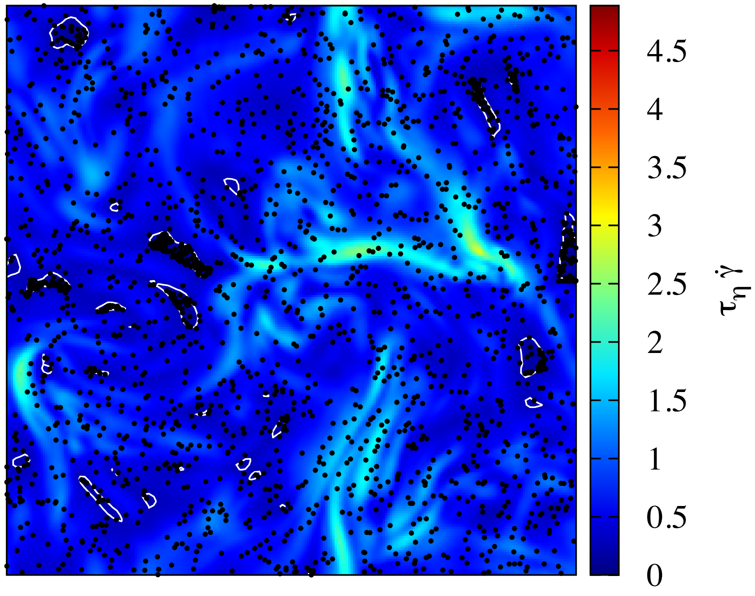
$$D = \lim_{r\to 0} \frac{\log C(r)}{\log r}$$



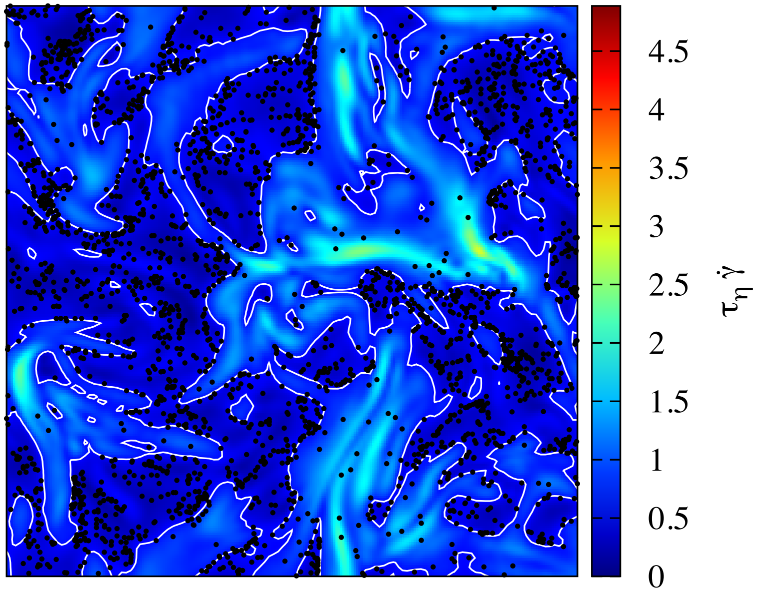
$D_2 \approx 1$ $D_2 \approx 2$ $D_2 = 3$

Maxey JFM87, Squires & Eaton PF91, Fessler Eaton IJMF94

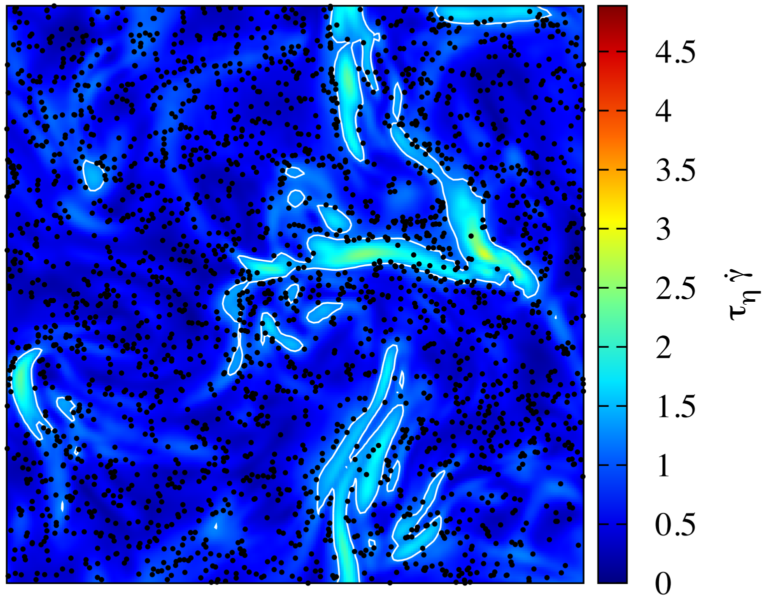
Analysis



$\tau_\eta \dot{\gamma}_T = 0.35$



$\tau_\eta \dot{\gamma}_T = 0.92$



$\tau_\eta \dot{\gamma}_T = 1.77$

2D slice of thickness η

Movie