

Copepods in turbulence: laboratory velocity and acceleration studies using high speed cameras

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EGU

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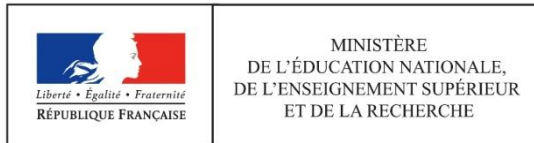


Action 1.4

Dynamics and transport of particles and plankton

PI: François Schmitt

General objectives: understand better the influence of turbulence on plankton, especially zooplankton (copepods). Two aspects: laboratory study and field study.

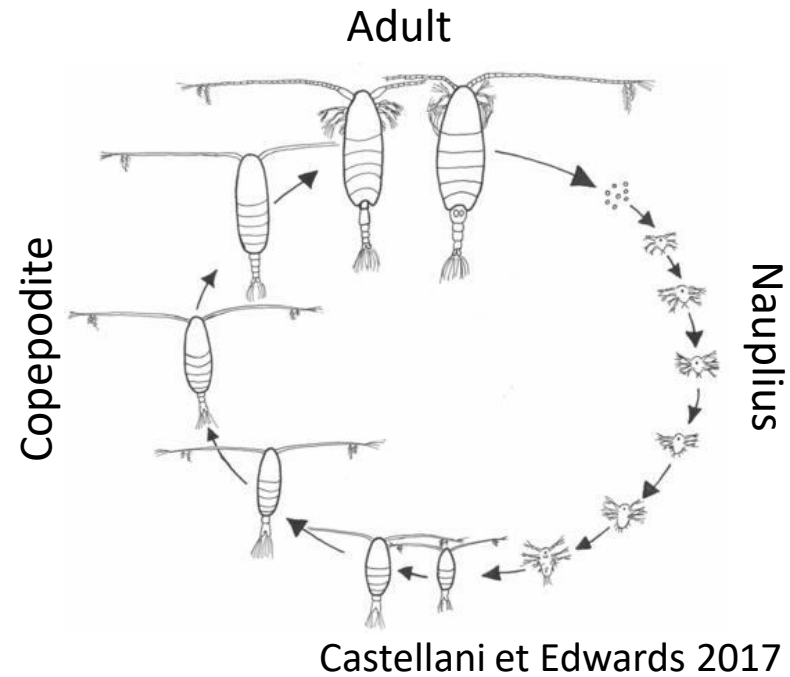
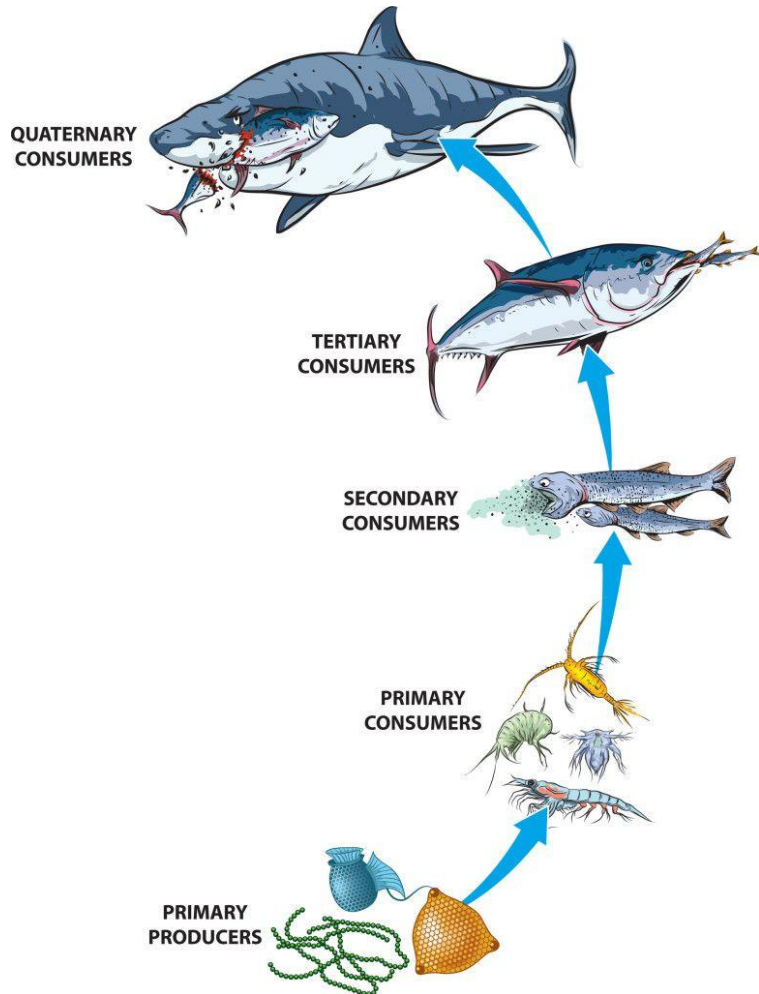


Outlines

- (1) Introduction about copepods
- (2) The turbulence experimental system of the marine station in Wimereux : Agiturb
- (3) Characterization of the flow with particles of different size
- (4) Characterization of copepod behavior

(1) Introduction about copepods

Marine Food Chain



Which behavior as a plankton?



11,500 species
Mauchline 1998

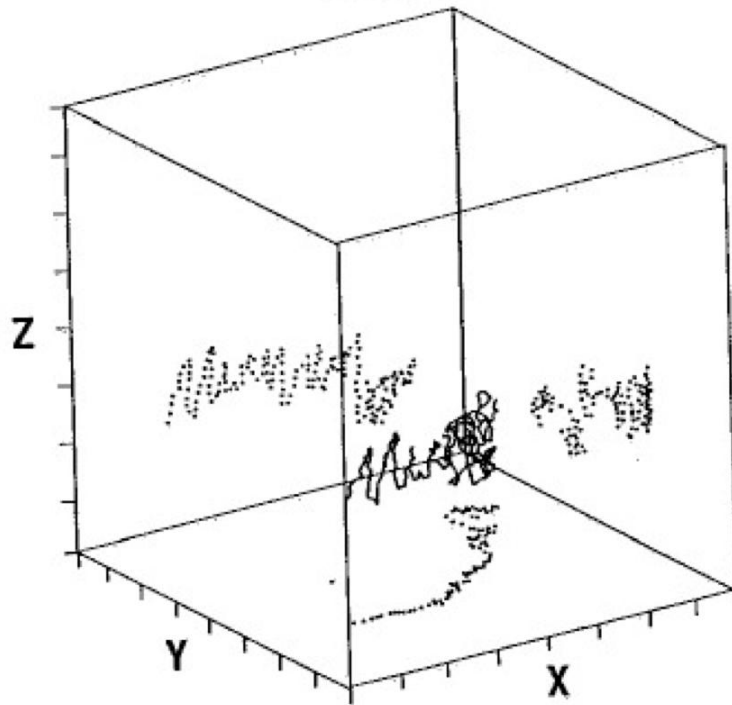
Copepods can swim

- (1) to feed or to escape
- (2) and to reproduce

Bundy et al., 1993

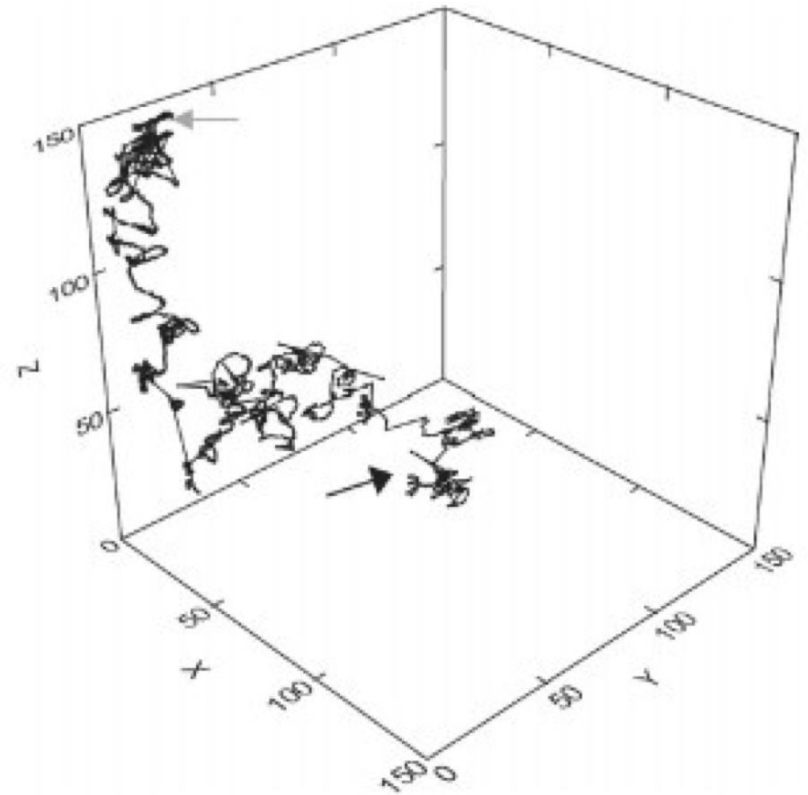
Centropages velificatus

Path Hi 1



Schmitt and Seuront, 2001

Temora longicornis



Buskey et al., 2002

Acartia spp.

Jumps last about 7 ms at 50 cm.s^{-1}
 → jumps of 3,5 mm
 → 3 to 6 times their size

$$V_{\text{mean}} = 40 \text{ cm.s}^{-1}$$

$$A_{\text{mean}} = 100 \text{ m.s}^{-2} = 10 \text{ g}$$

$$V_{\text{max}} = 80 \text{ cm.s}^{-1}$$

$$A_{\text{max}} = 300 \text{ m.s}^{-2} = 30 \text{ g}$$





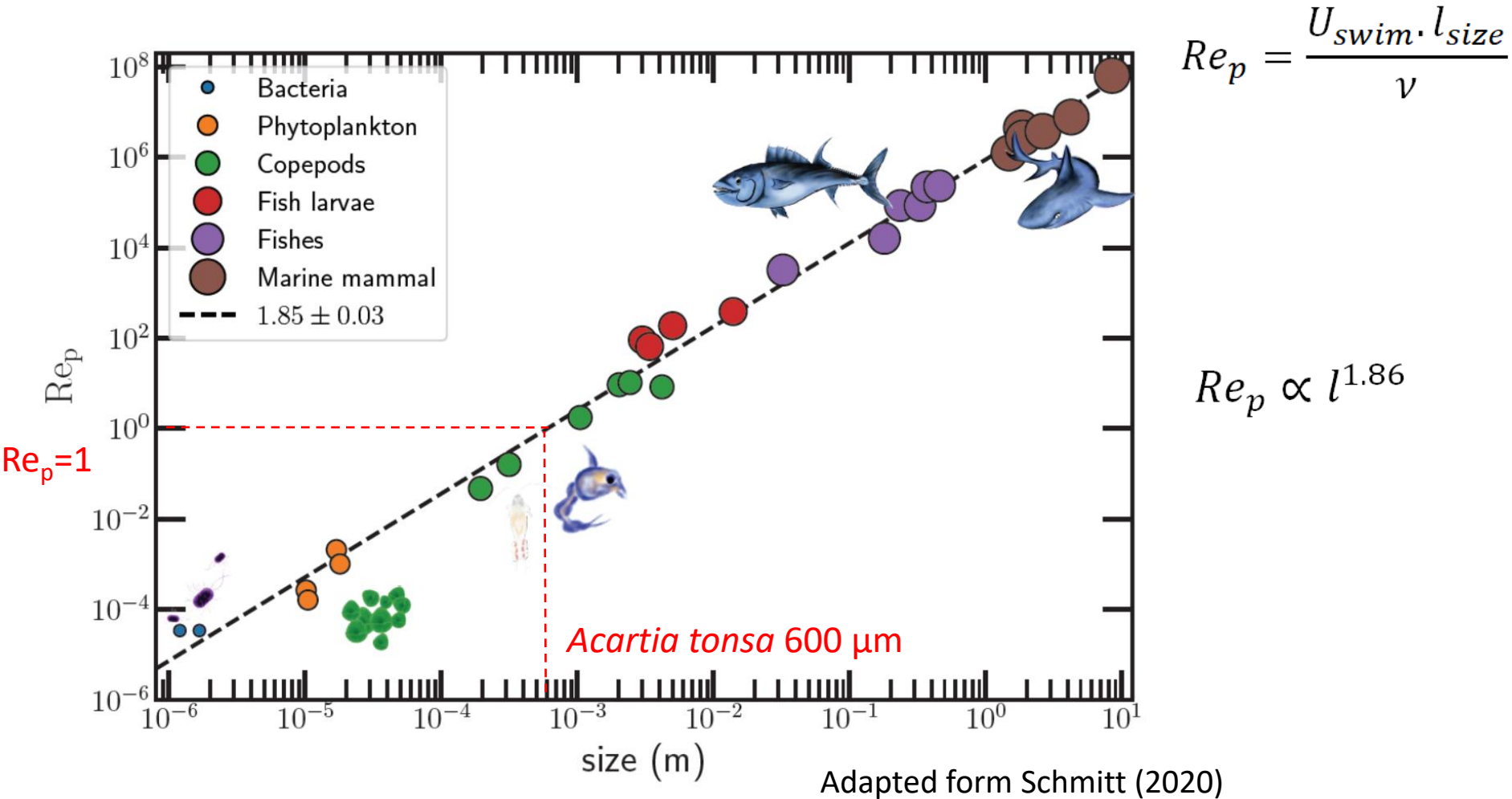
Acartia tonsa

Copepods swim by making very fast jumps thanks to their antennae and their oar

Swimming behavior in live



Particulate Reynolds number for swimming animals



$Re_p \gg 1$ Swim in a turbulent environment

$Re_p \sim 1$ Swim either in a turbulent or a viscous environment

$Re_p \ll 1$ Swim in a viscous environment

Copepods use the advantage of living on the border of different worlds

- low Re for feeding
- large Re for escape

Reference: *Biol. Bull.* **198**: 213–224. (April 2000)

Life in Transition: Balancing Inertial and Viscous Forces by Planktonic Copepods

JEANNETTE YEN

*Marine Sciences Research Center, State University of New York at Stony Brook,
Stony Brook, New York 11794-5000*

Naganuma (1996)

Yen (2000)

Turbulence and encounter rate predator/prey

- Swim given to a cost-benefit balance
- How does turbulence influence this balance?

Rothschild Osborn Model

$$Z = N(\pi R^2) \frac{U^2 + 3V^2 + 4W^2}{3\sqrt{V^2 + W^2}}$$

Z : Encounter rate

N: preys density ($\#/m^3$)

R: Distance of detection

V: Predator swimming speed (cst)

U: Preys swimming speed (random direction)

W: Gradient of turbulent speed at the scale R

Encounter rate
(Ingestion rate)



Turbulence intensity

Rothschild et Osborn 1988

Kioboe et al. 1995

Gilbert et al. 2005

Turbulence and encounter rate predator/prey

- Swim given to a cost-benefit balance
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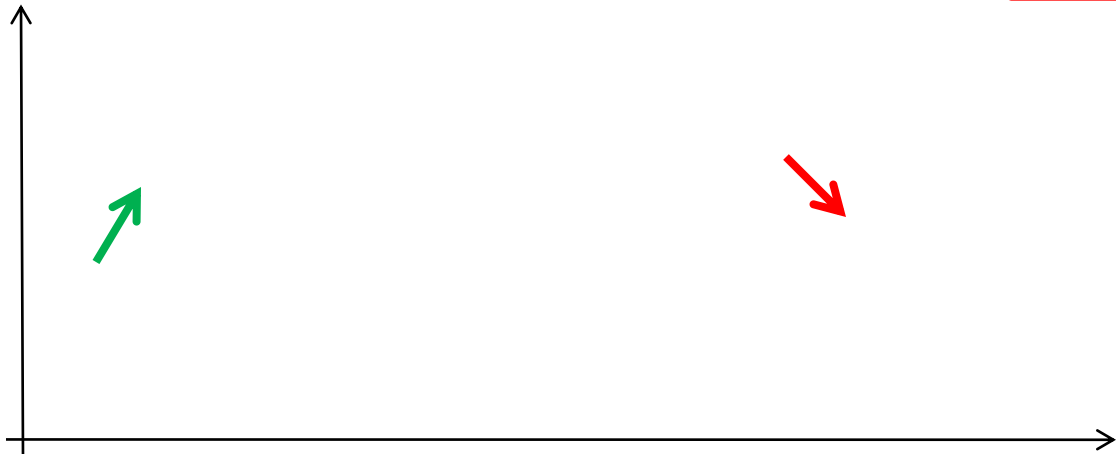
Rothschild Osborn Model

$$Z = N(\pi R^2) \frac{U^2 + 3V^2 + 4W^2}{3\sqrt{V^2 + W^2}}$$

Disturbed Feeding current
Disturbed detection of preys
(chemoreception)
Disturbed detection of predators
(mecnoreception)

Preys capture $\searrow$
Predators escape $\searrow$

Encounter rate
(Ingestion rate)



Turbulence intensity

Rothschild et Osborn 1988
Kioboe et al. 1995
Gilbert et al. 2005

Turbulence and encounter rate predator/prey

- Swim given to a cost-benefit balance
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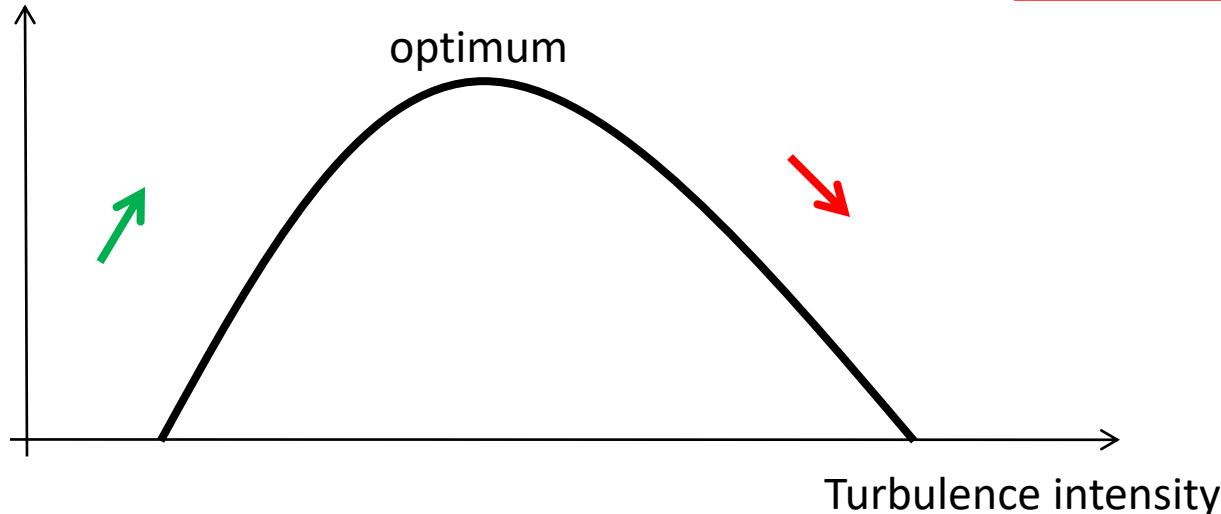
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Rothschild et Osborn 1988
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Gilbert et al. 2005

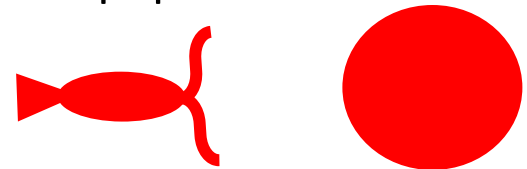
Two leading questions

- « Dome » shape : is there an optimal turbulence ?
- What are the impacts of turbulence on copepods behavior?

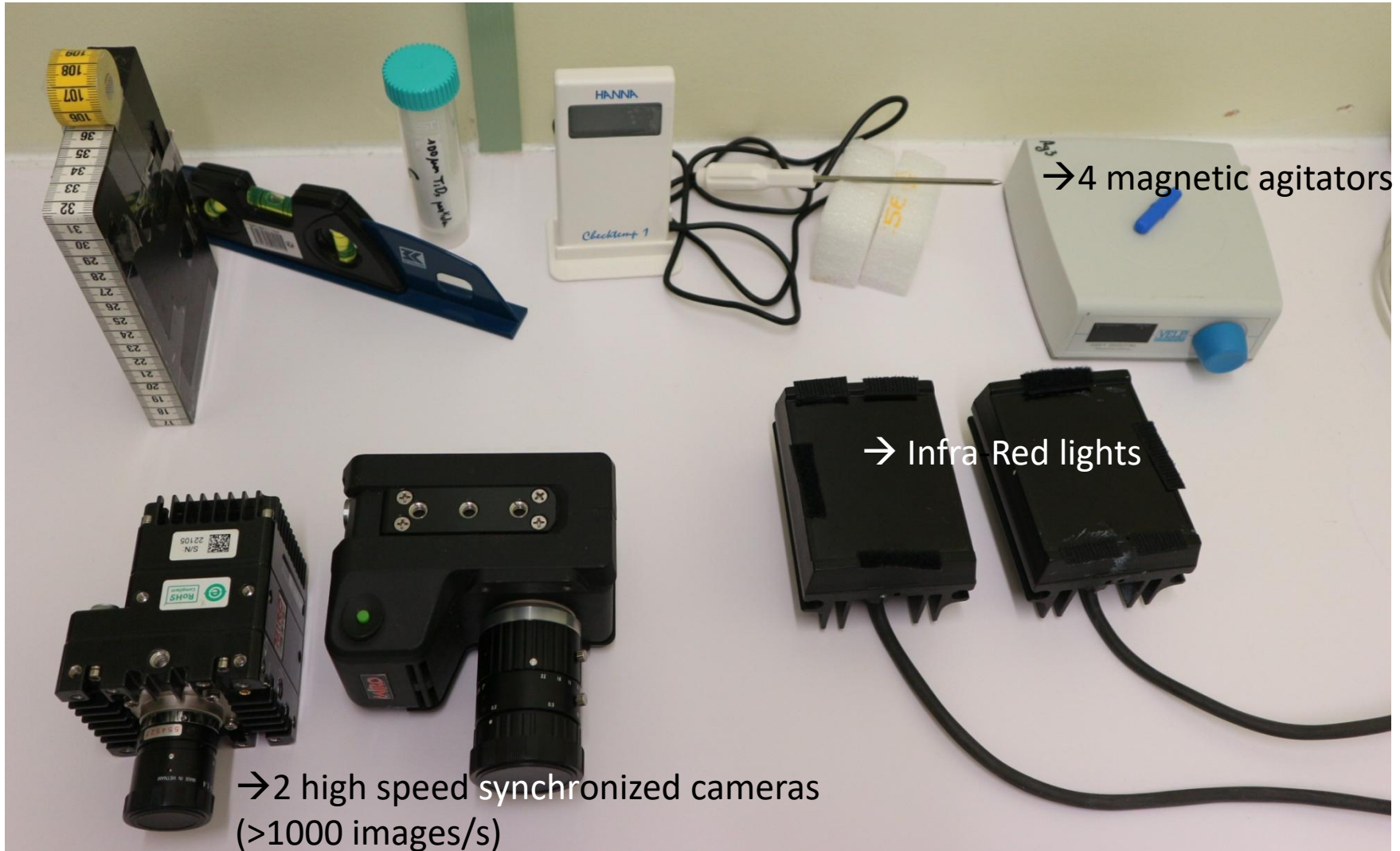
We built an experimental system to generate controlled turbulence of different intensities

We have placed copepods in the system and recorded their behavior

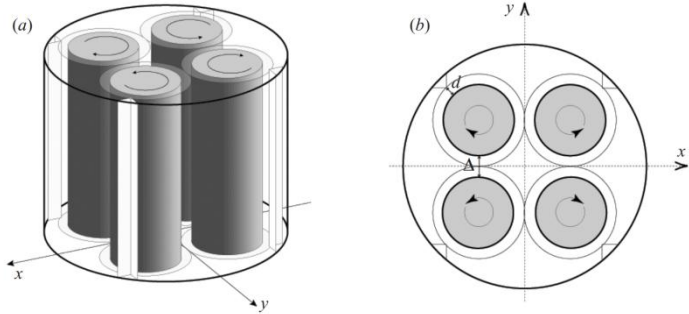
- In case of difference between dead and alive copepods?
 - Indication of swimming behavior
- In case of difference between particles and dead copepods of the same size ?
 - Indication of difference in shape



(2) The turbulence experimental system of the marine station in Wimereux : Agiturb

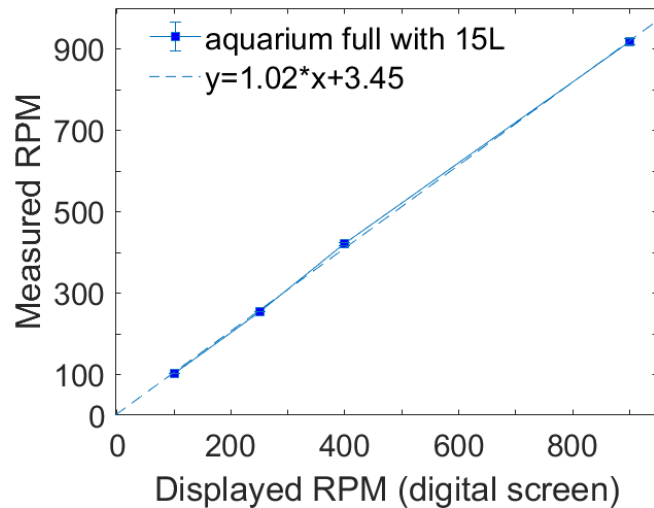


Taylor Four-roller mill (Taylor, 1934)

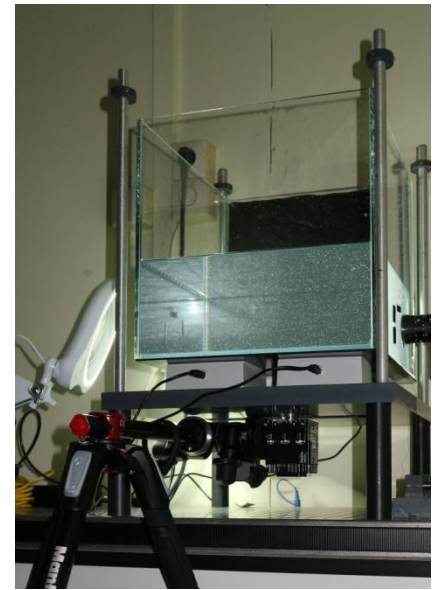


Andreotti et al. (2001)

Calibration curve of the stirring bars

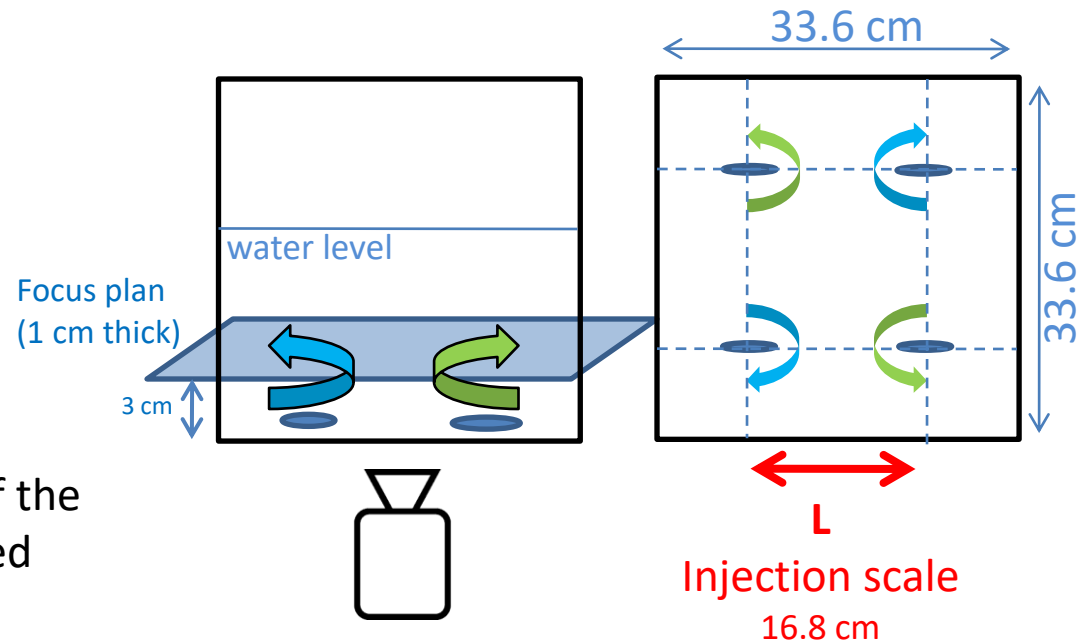


Measured RPM (number of rotations of the stirring bars) correspond to the expected values (digital screen)

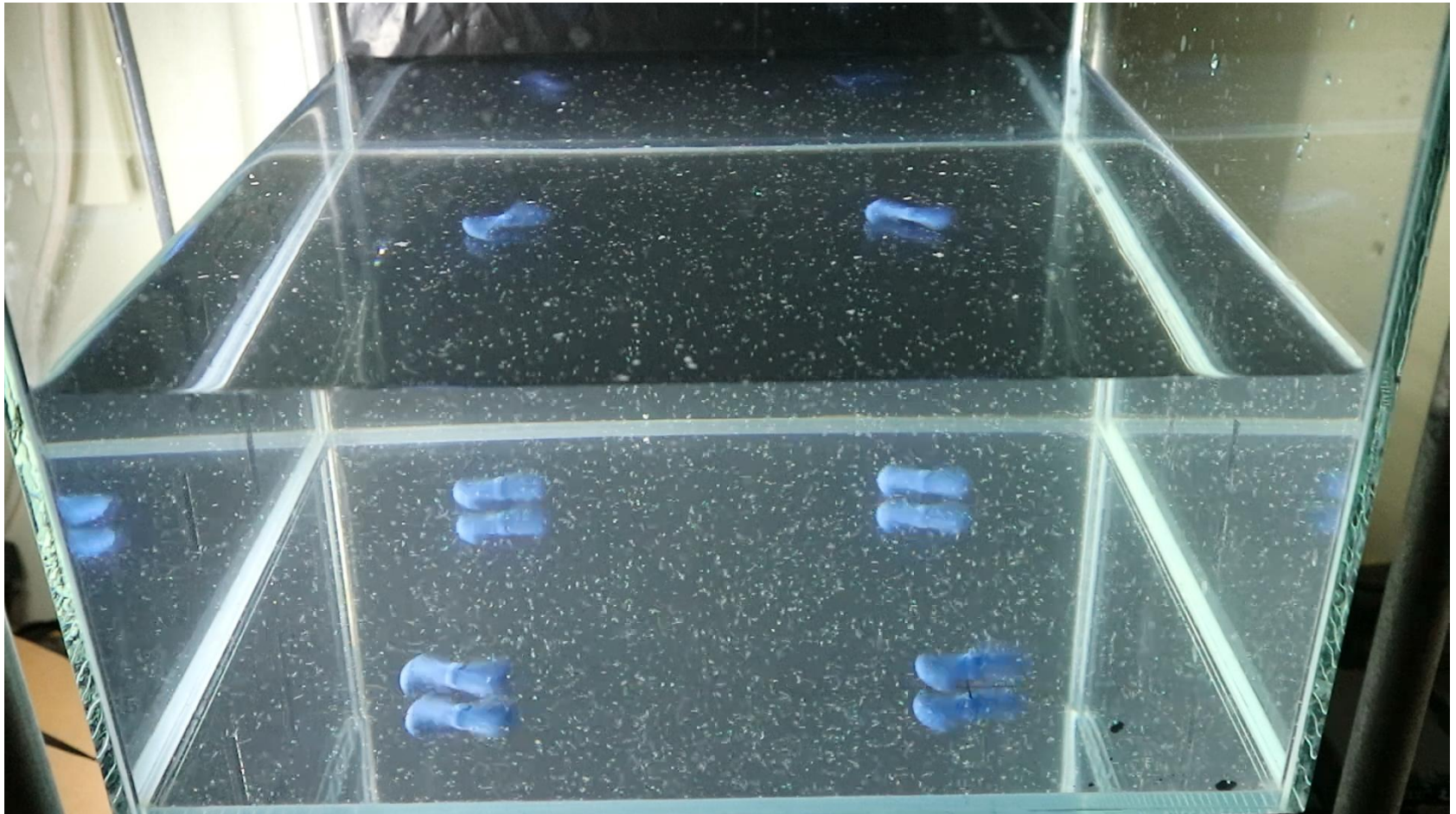


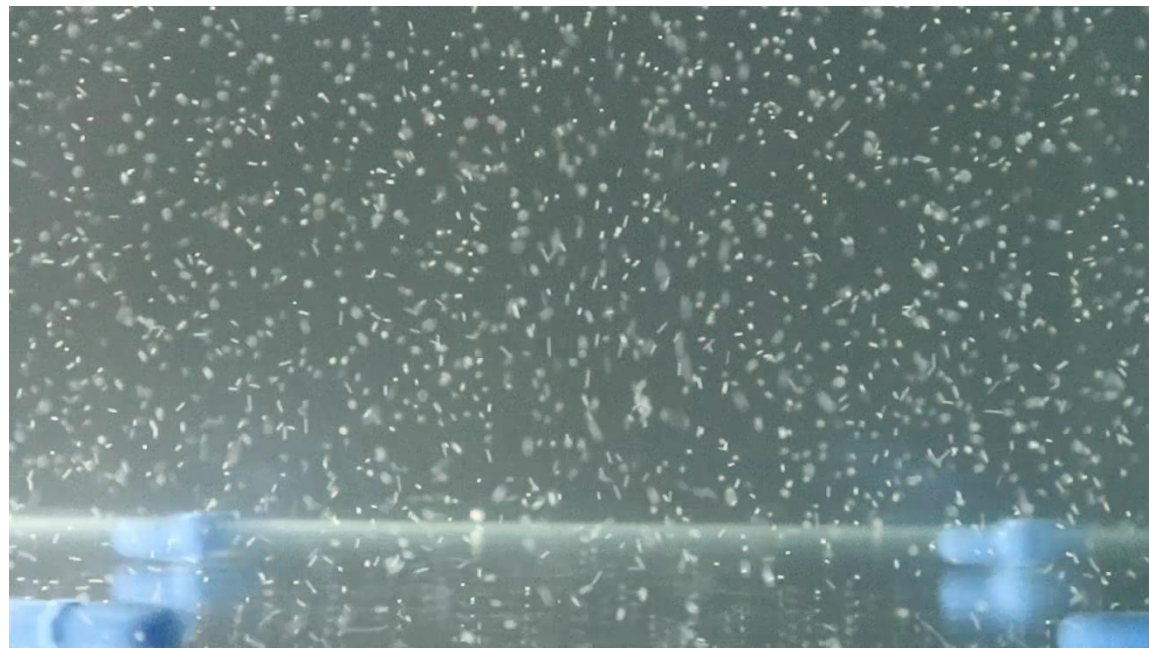
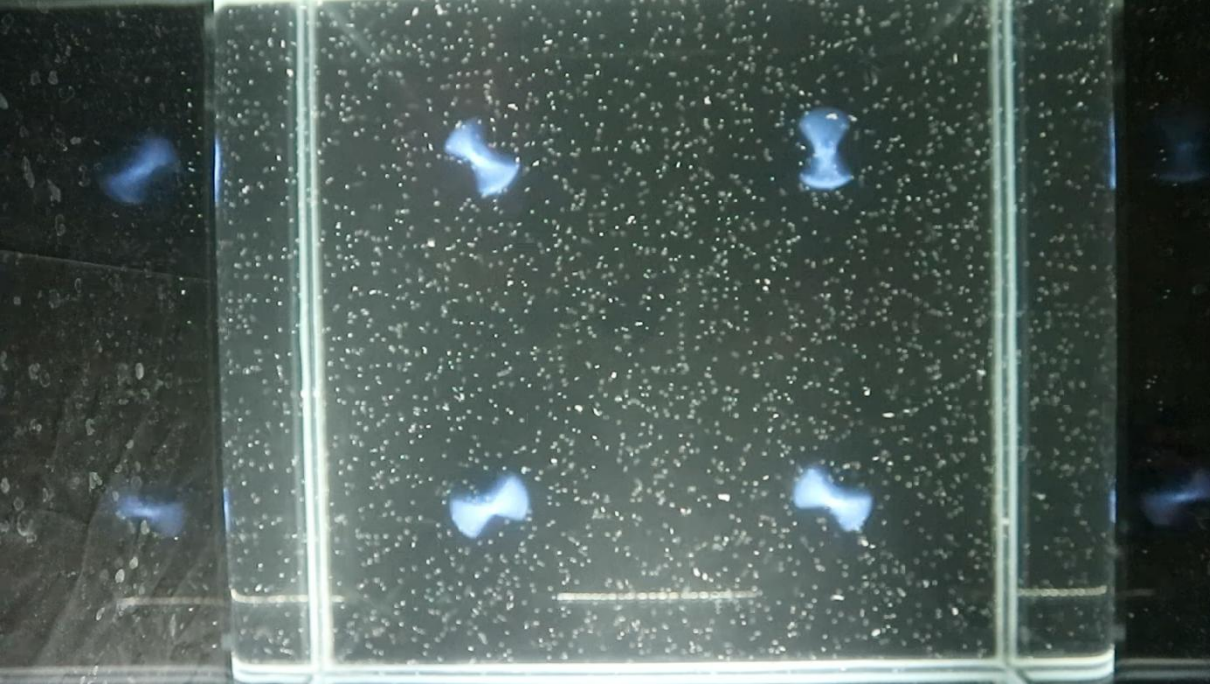
Side view

Bottom view

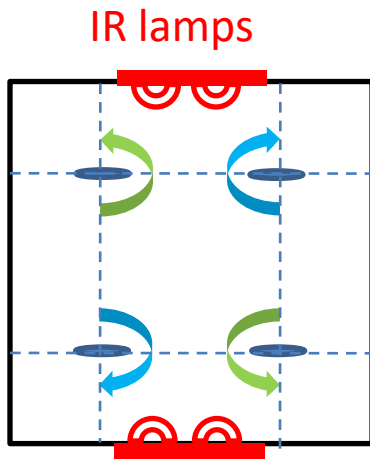


Macroscale structures of the flow

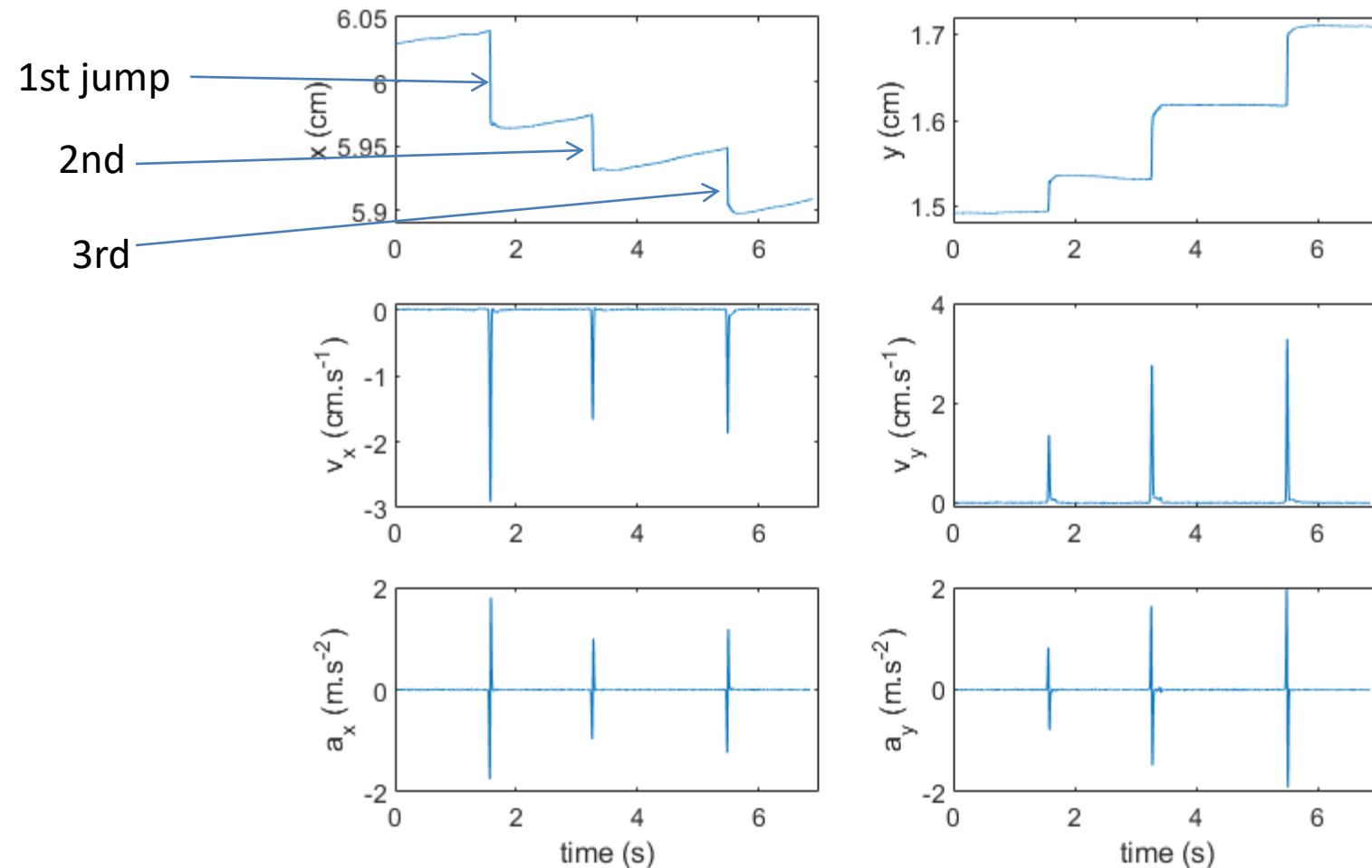




- Why high speed camera? → to catch high speed records
- Why IR light? → to avoid phototaxis

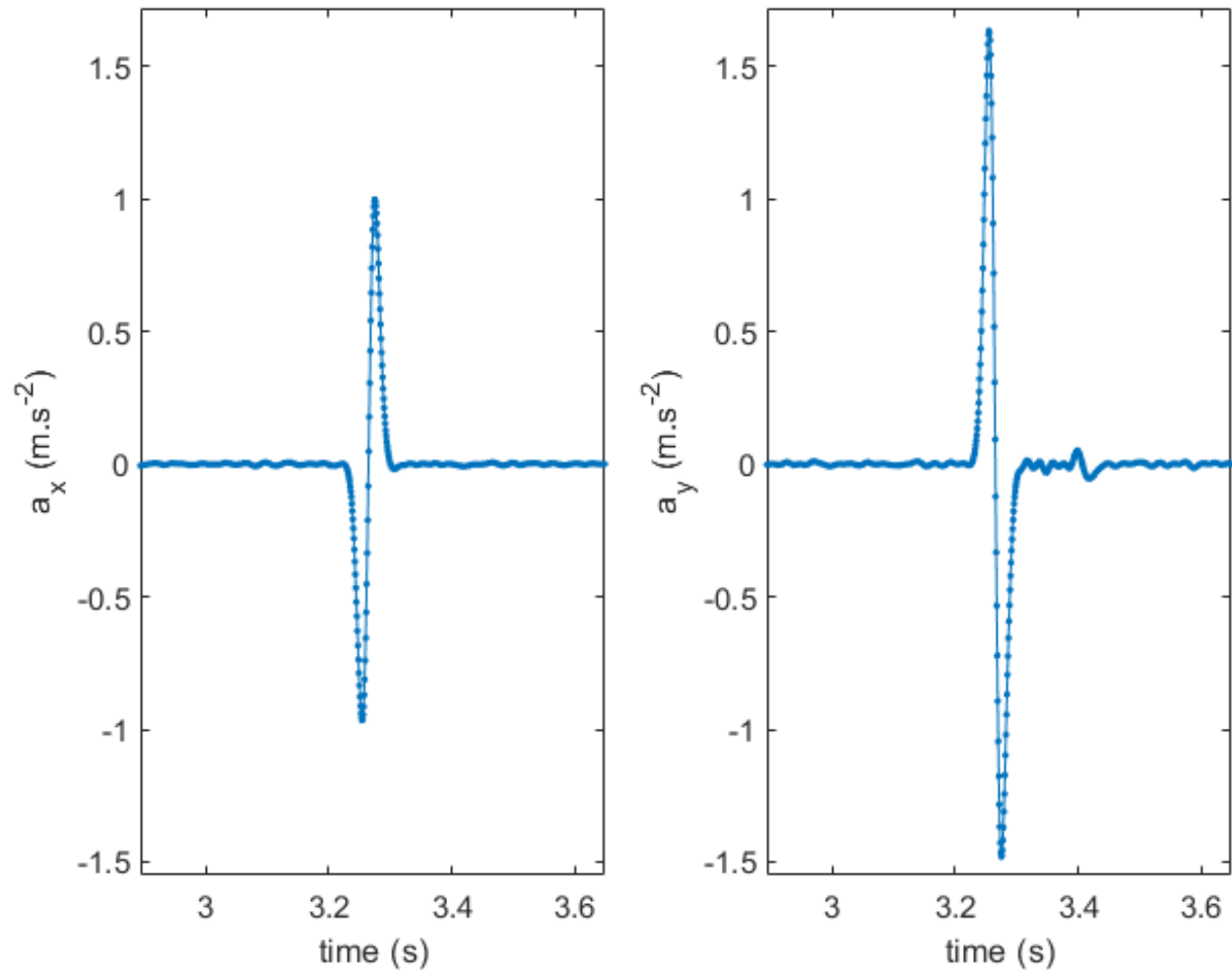


High-speed cameras are able to resolve very fast jumps



Example of three successive jumps visible in the coordinates recorded on the XY plan.
Corresponding velocity and acceleration.

Acceleration is well resolved during jumps



(3) Characterization of the flow with particles of different size

We aim at reproducing a
pure
extensional
flow
with Agiturb

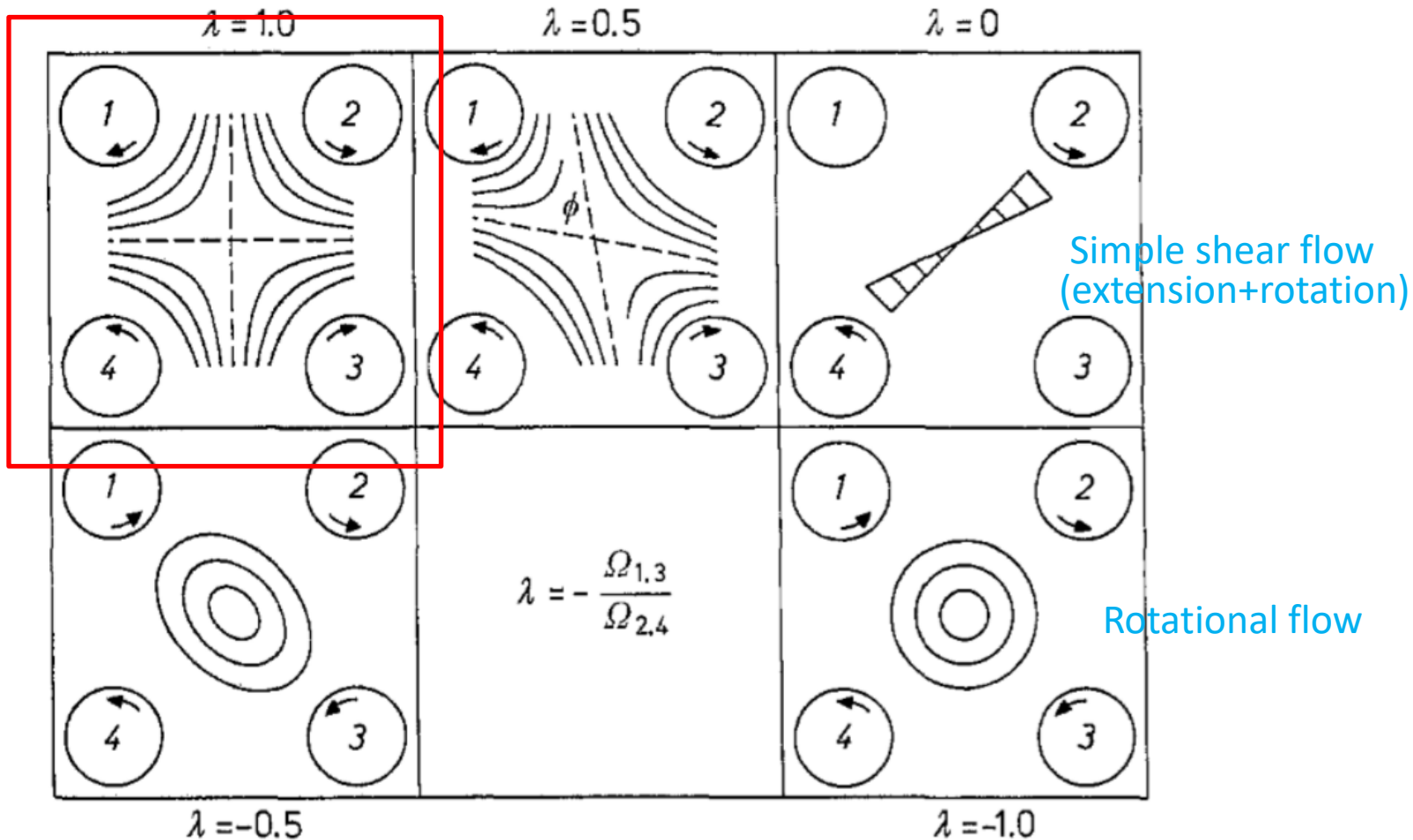
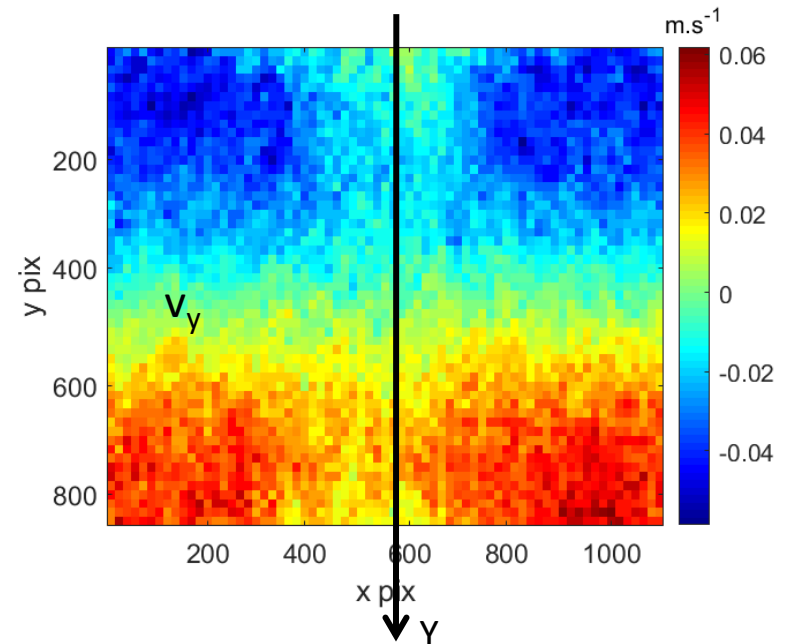
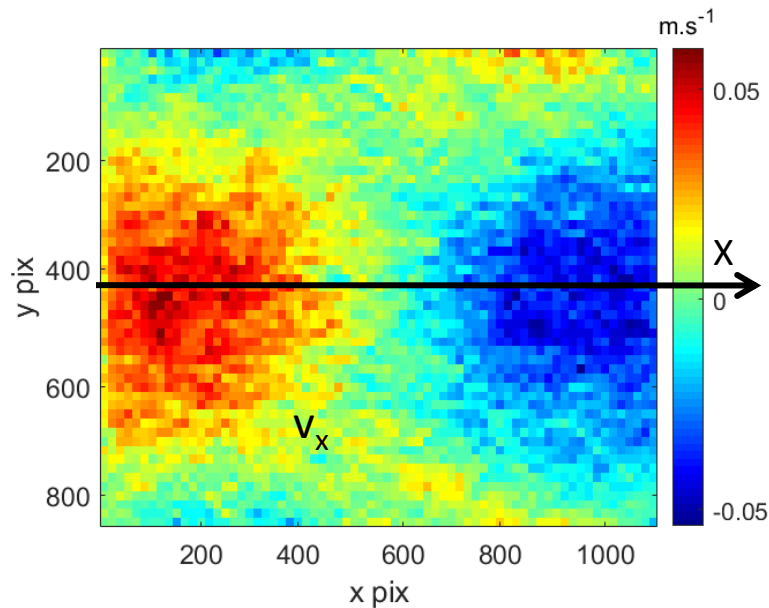
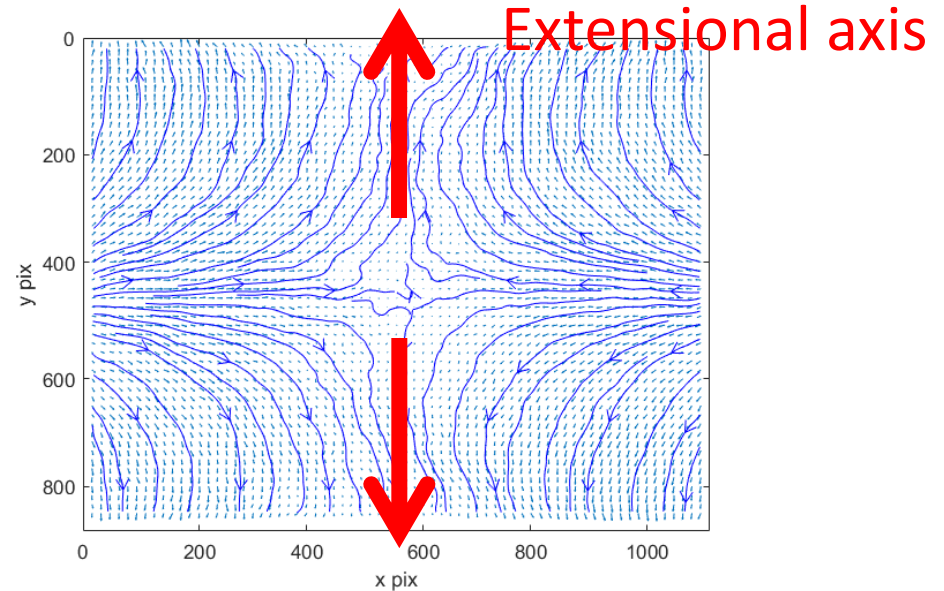


Fig. 1. Streamlines of homogeneous two-dimensional flows

Lagrangian tracking in 2D

Velocity components of
particles in the flow (diameter
 $600\mu\text{m}$ at 900rpm)

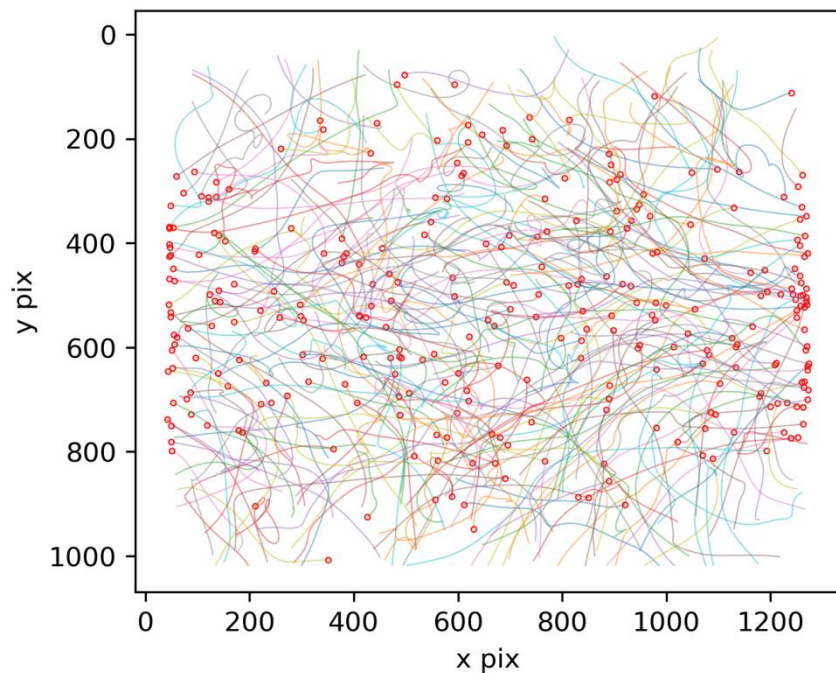


Reconstitution of the 2D trajectories with TrackPY in Python

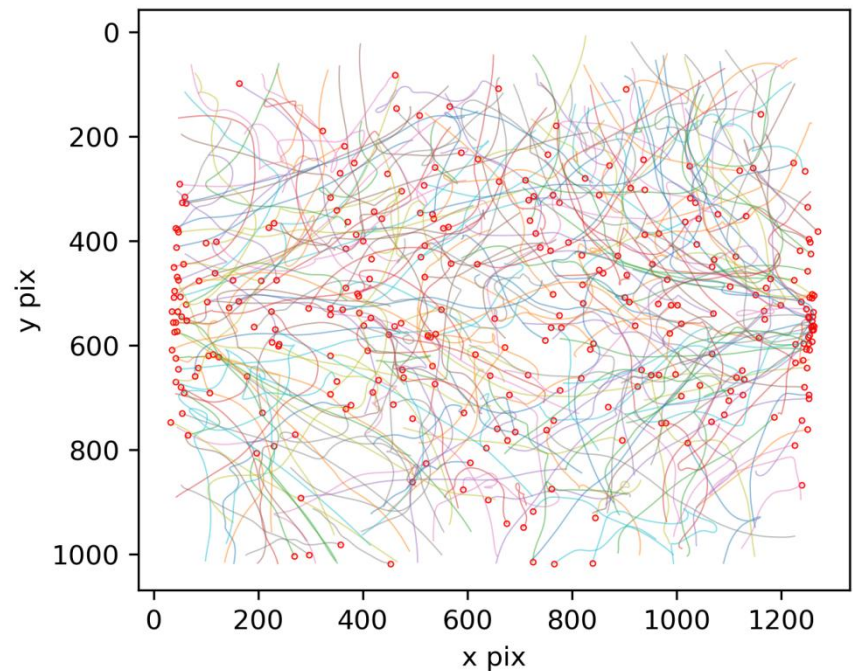
- Track blob-like features in video images, follow them through time, and analyze their trajectories.
- 3 steps :
 - *Feature finding* : initial feature coordinates are obtained from the images.
 - Size, separation between two different blobs, intensity
 - *Refinement* : sub-pixel precision is obtained in coordinate.
 - Least-squares fitting with a radial model function to locate the center-of-brightness
 - *Linking* in time of the coordinates.
 - A prediction framework (NearestVelocityPredict) relates the coordinates that are the closest and that have matching displacement directions
 - About the center-of brightness : How far away can it move? How long can it take to appear again?

Trajectories of the polystyren particles reconstructed with TrackPY (Python)

400rpm

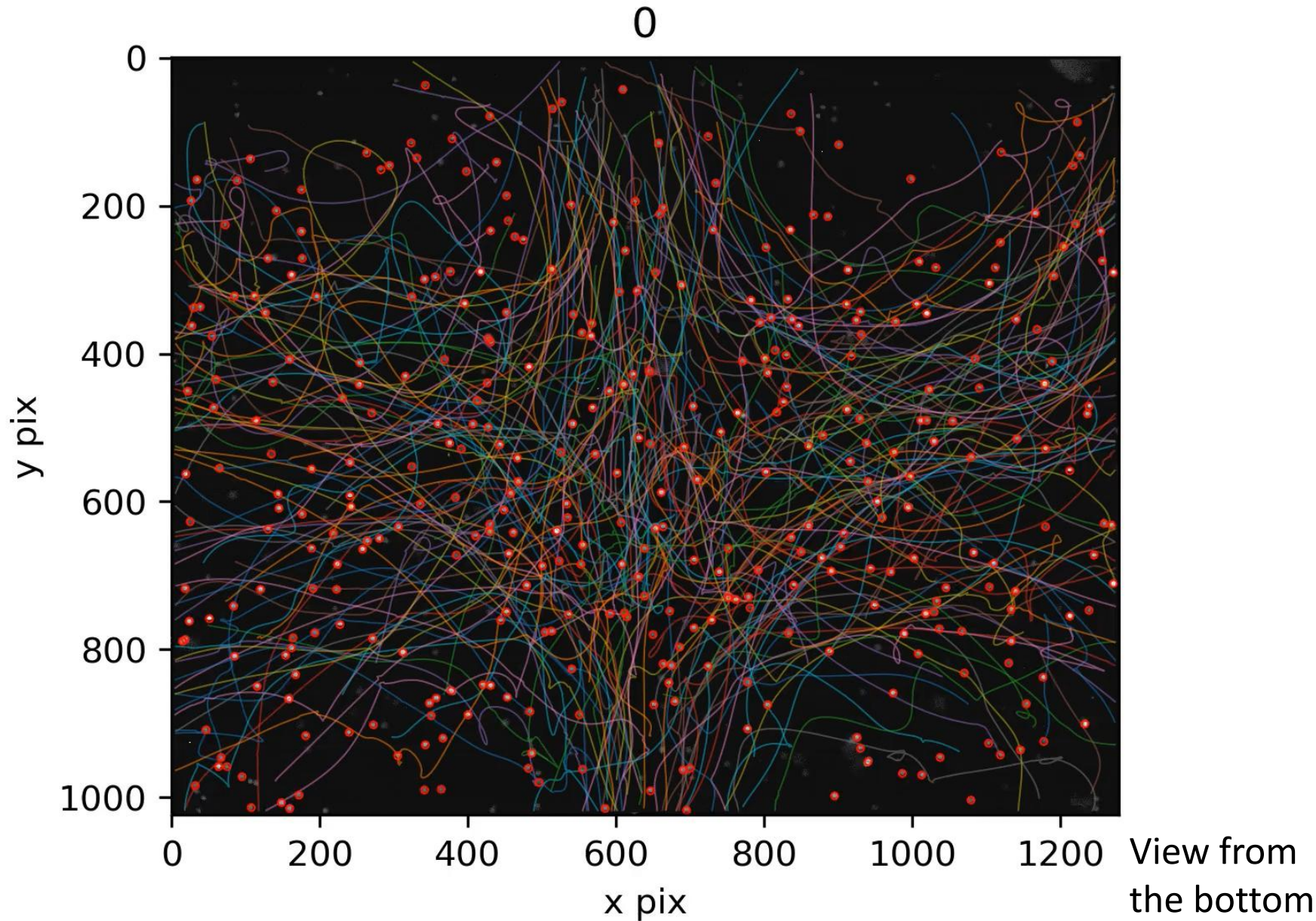


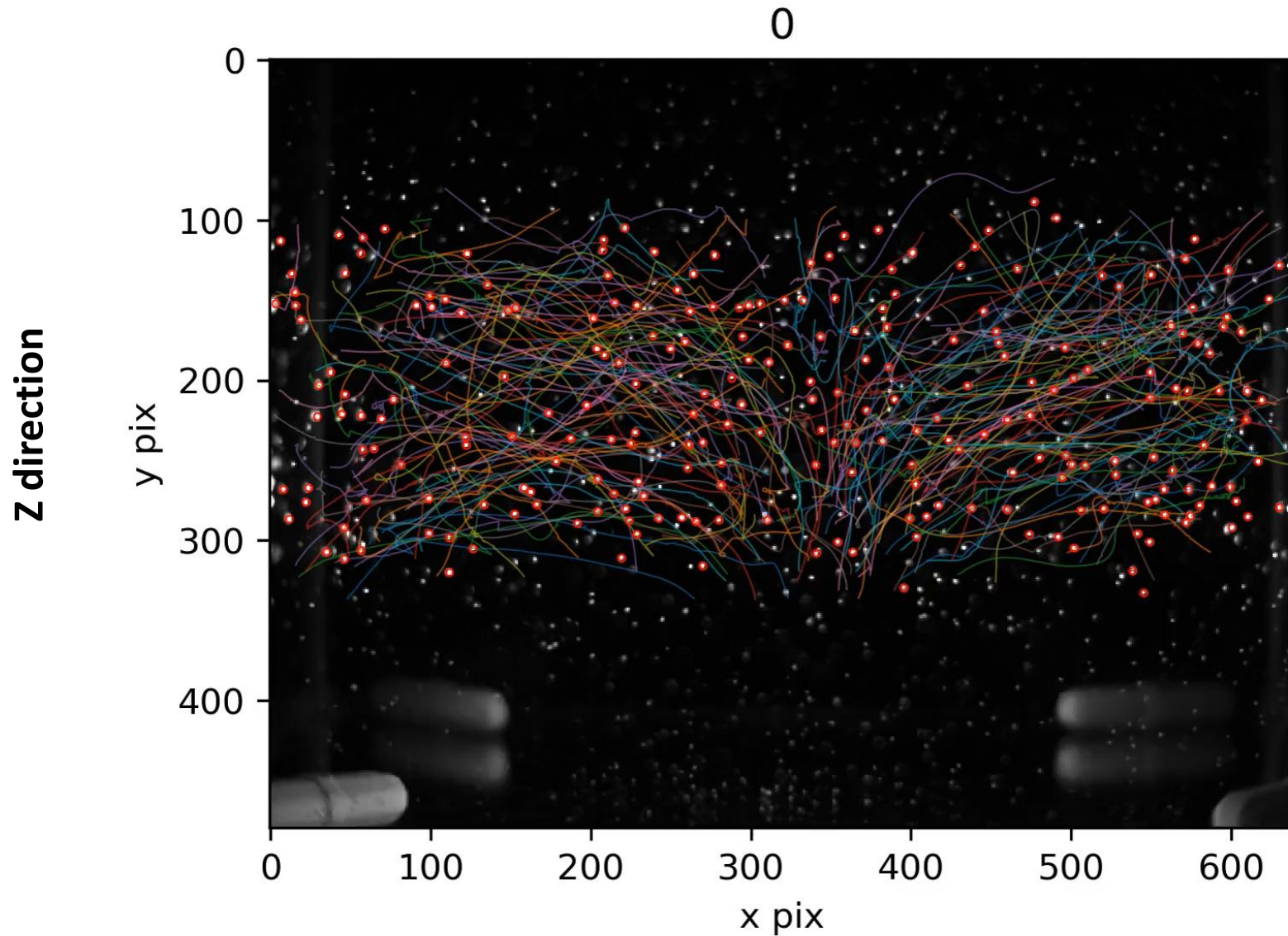
900rpm



All of the detected particles are following as their own trajectory (red dot at the beginning of the corresponding trajectory)

Motion is erratic in the central area





On the vertical axis, the flow is anisotropic : upward panach

View from
the side

Signal processing

- Background subtraction

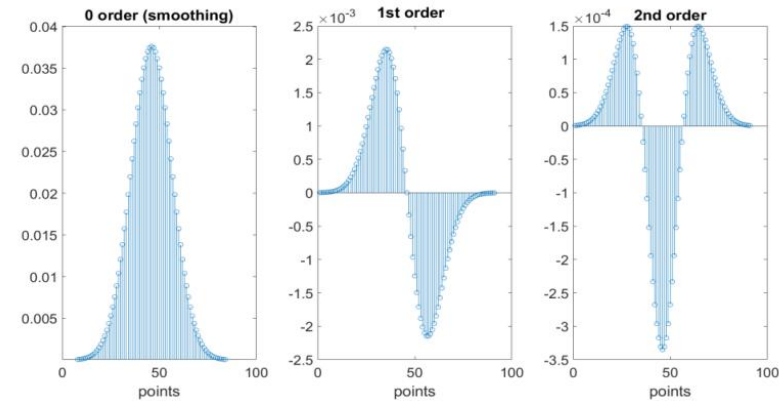
- Gaussian kernel

$$g(\tau) = \frac{1}{\sqrt{\pi} \cdot \omega^2} \cdot \exp\left(-\frac{\tau^2}{\omega^2}\right) \longrightarrow$$

τ_f = filter length

$$\tau_f = \sqrt{2} \cdot \omega$$

τ_f was chosen such as filtering the noise does not remove information at the Kolmogorov scale



Filter coefficient for convolution

Derivatives = convolution with the derivatives of the kernel

Eulerian measurements in 3D with particle of 10 μm

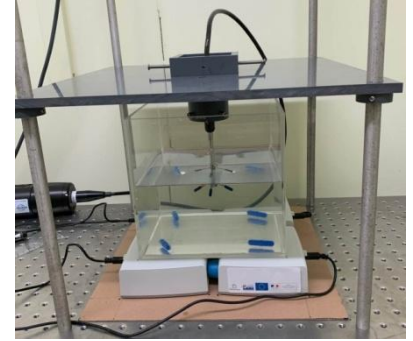
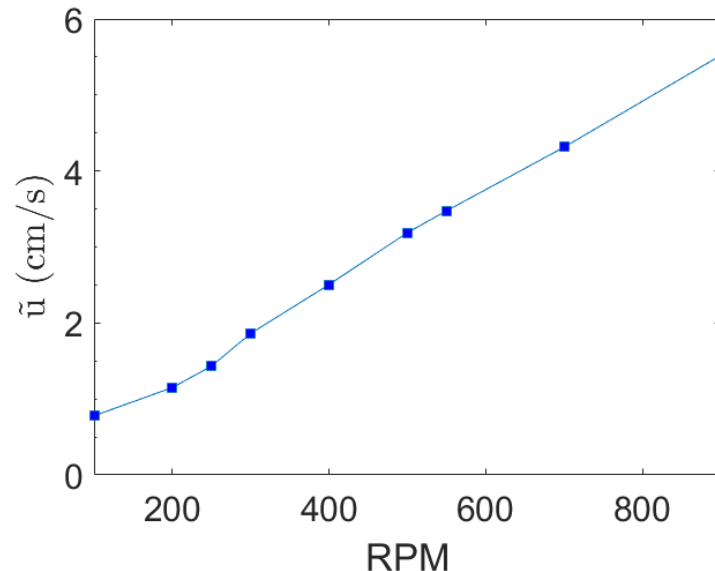
Fluctuating speed

$$v'_x = v_x - \langle v_x \rangle$$

$$v'_y = v_y - \langle v_y \rangle$$

$$v'_z = v_z - \langle v_z \rangle$$

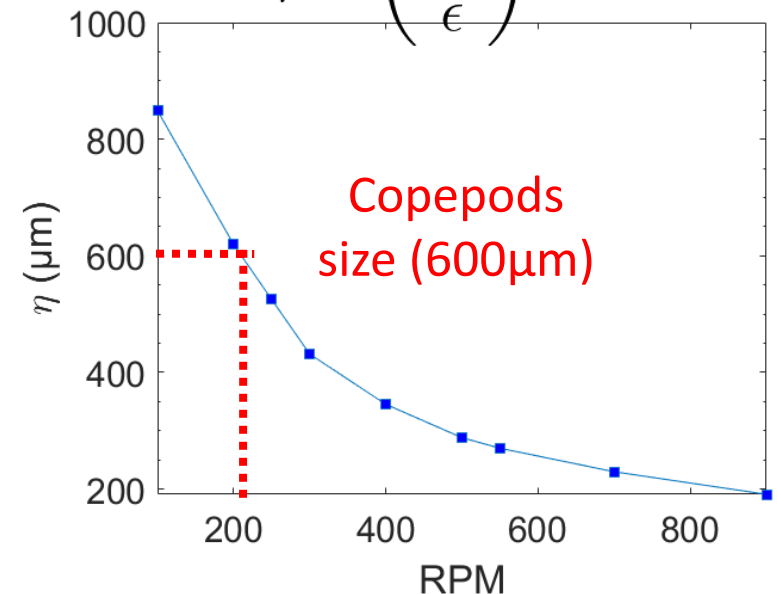
$$\tilde{u} = \frac{\sqrt{\langle v'^2_x \rangle} + \sqrt{\langle v'^2_y \rangle} + \sqrt{\langle v'^2_z \rangle}}{3}$$



ADV (Nortek Vectrino)

Kolmogorov scale

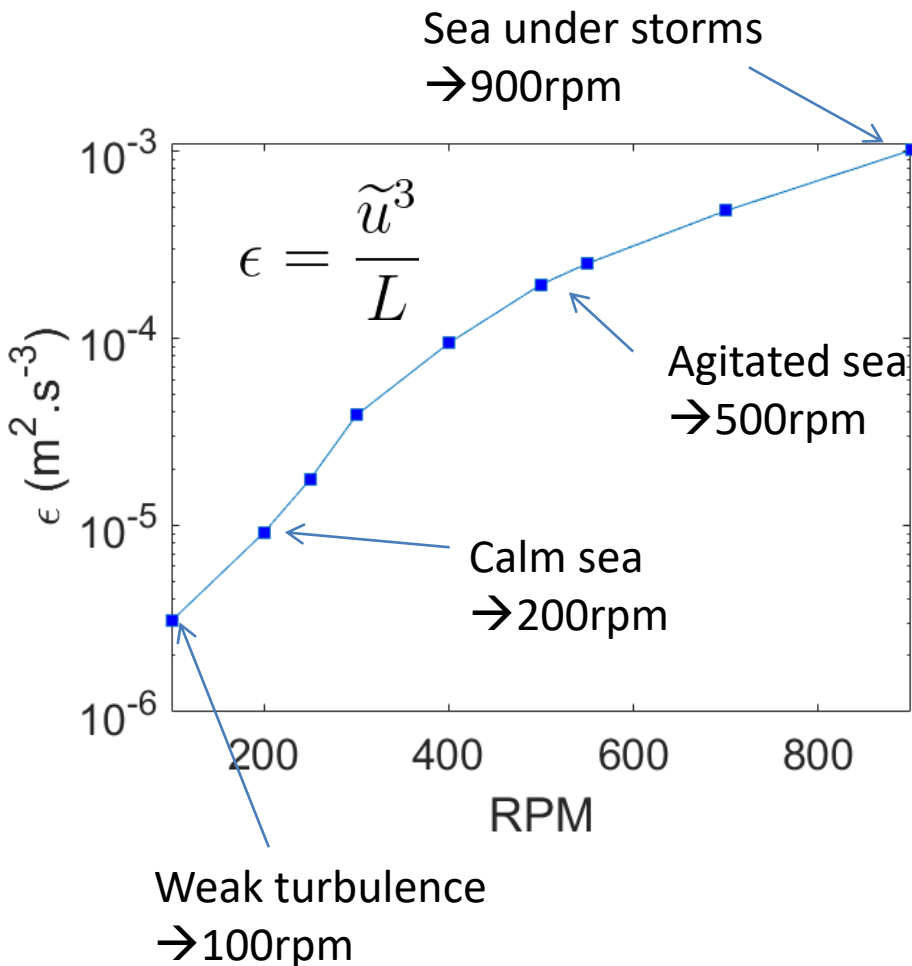
$$\eta = \left(\frac{\nu^3}{\epsilon} \right)^{1/4}$$



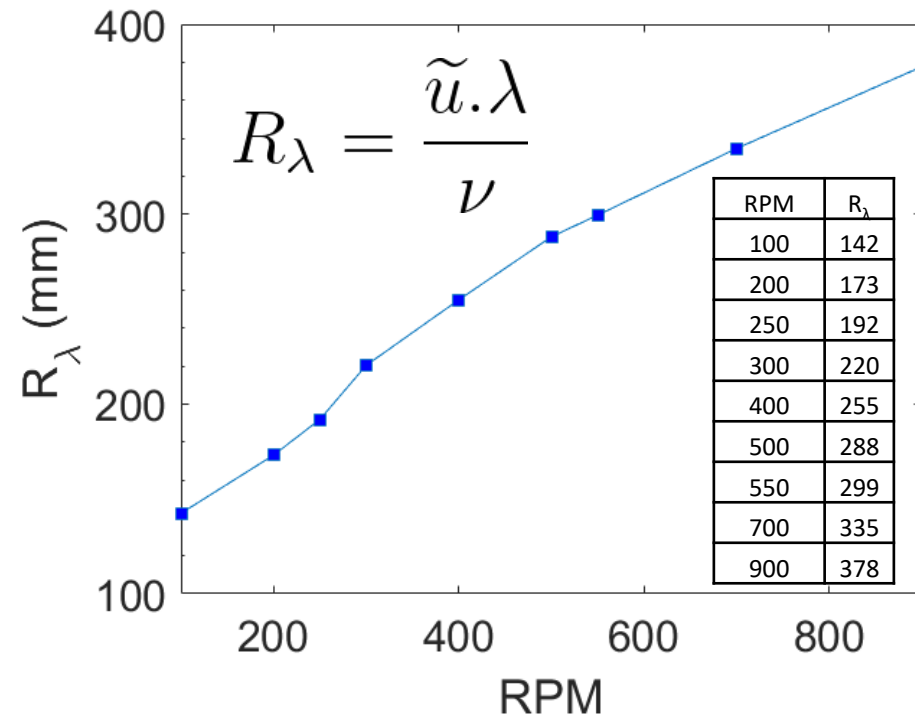
Kolmogorov scale decreases with turbulence intensity down to 200 μm

Comparison of the experimental turbulence with turbulence in natural conditions

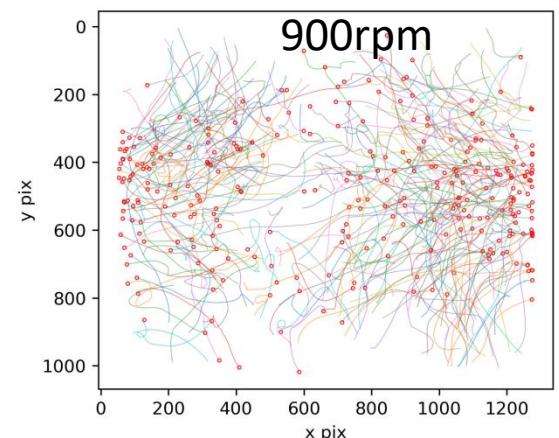
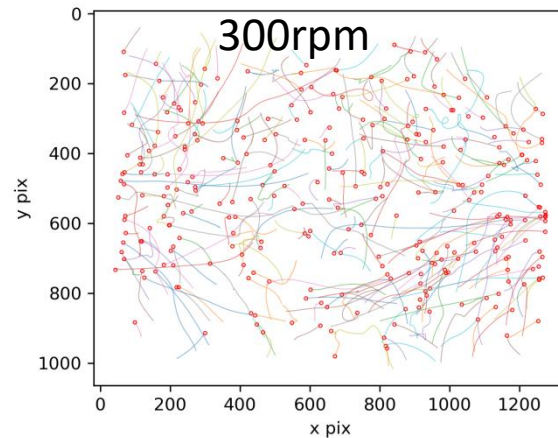
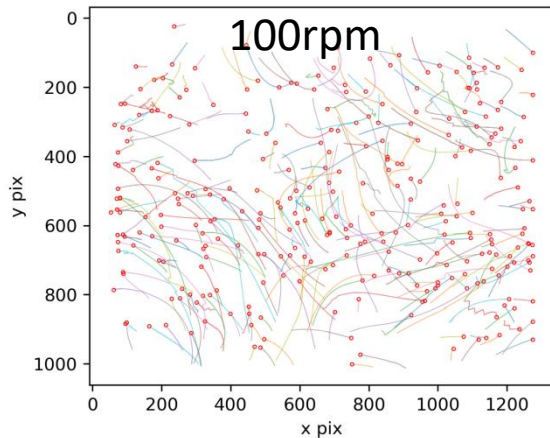
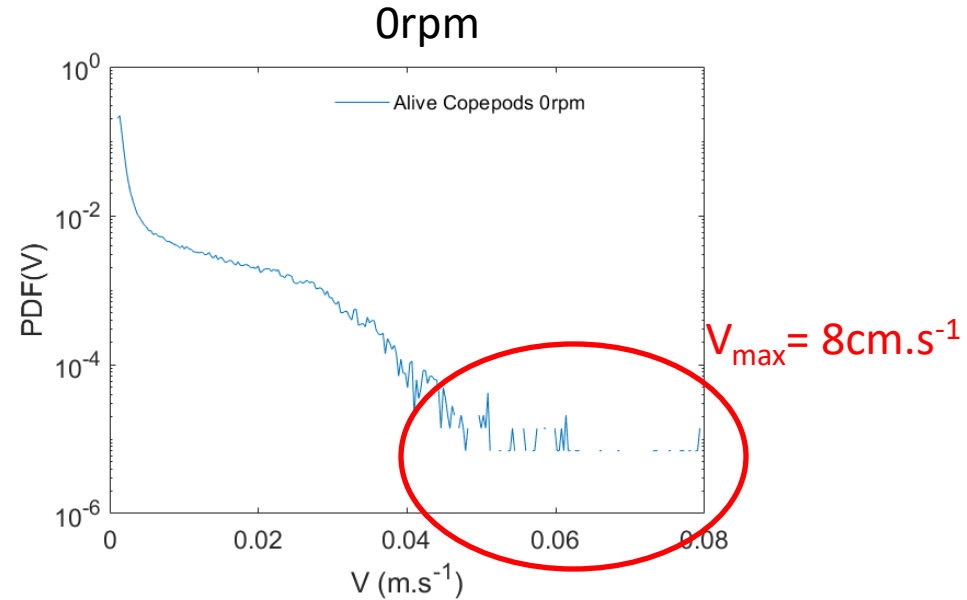
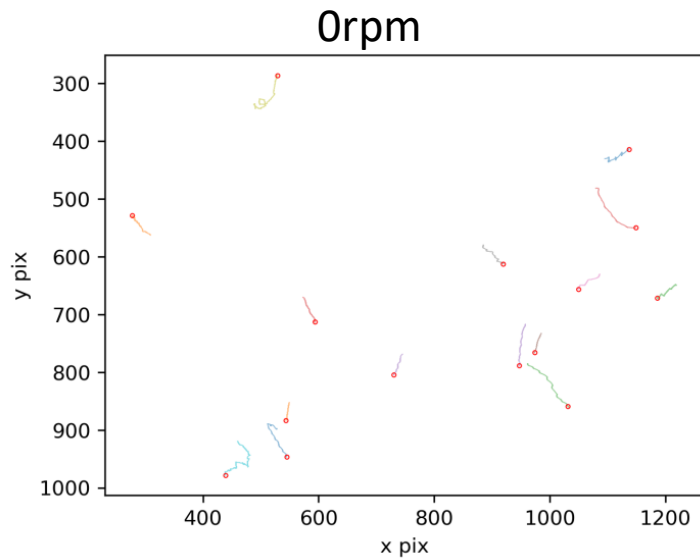
Dissipation rate



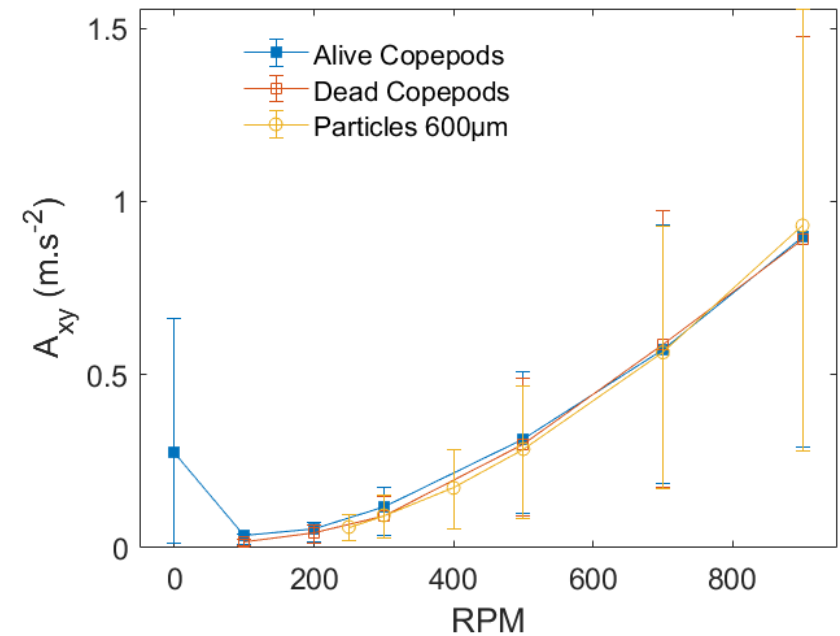
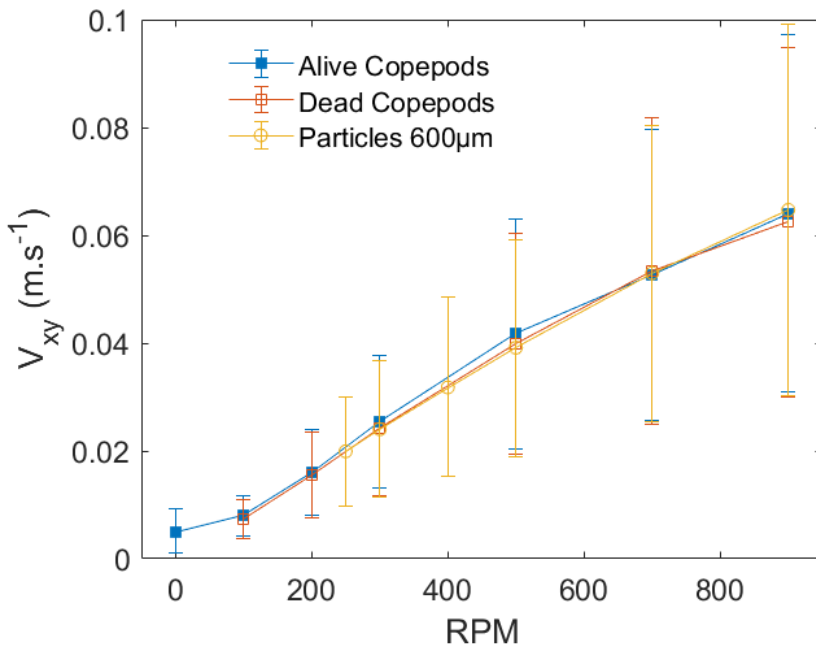
Taylor-based Reynolds number



(4) Characterization of copepod behavior

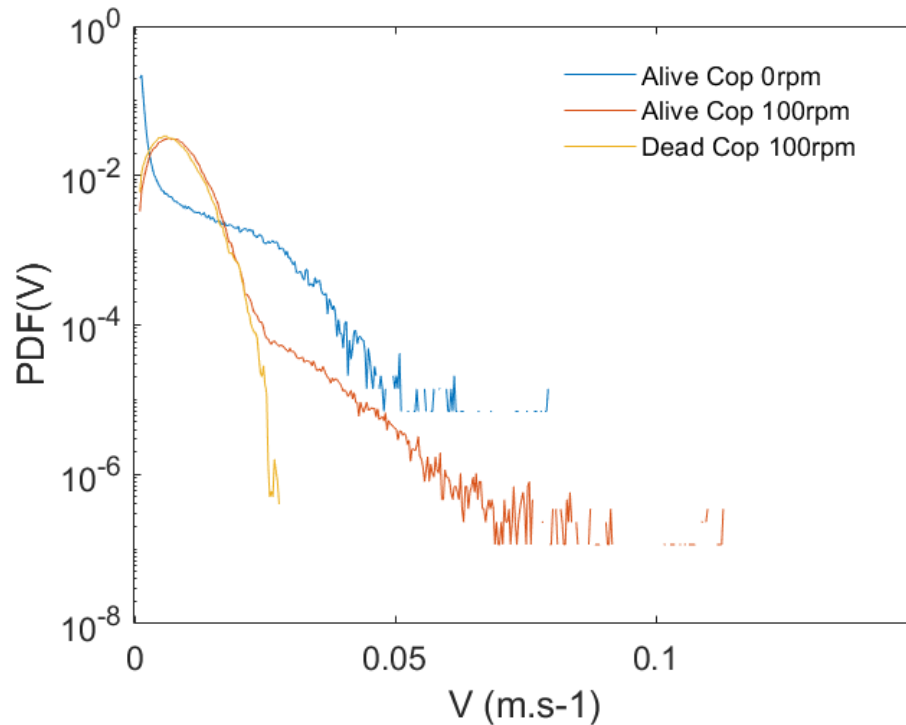


Mean values of velocity and acceleration moduli at different turbulence intensities

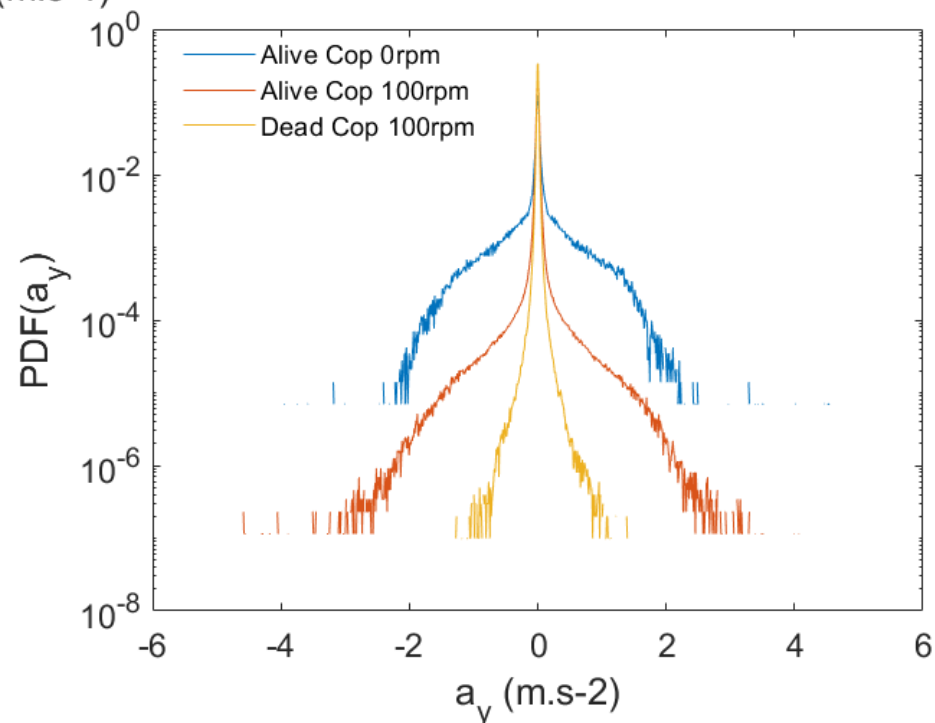
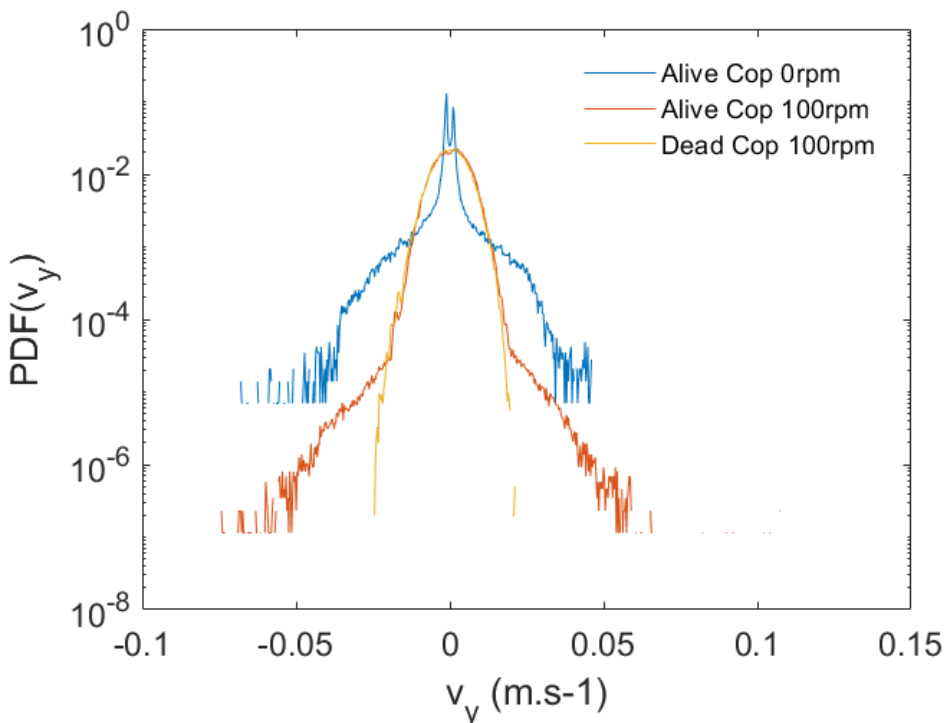


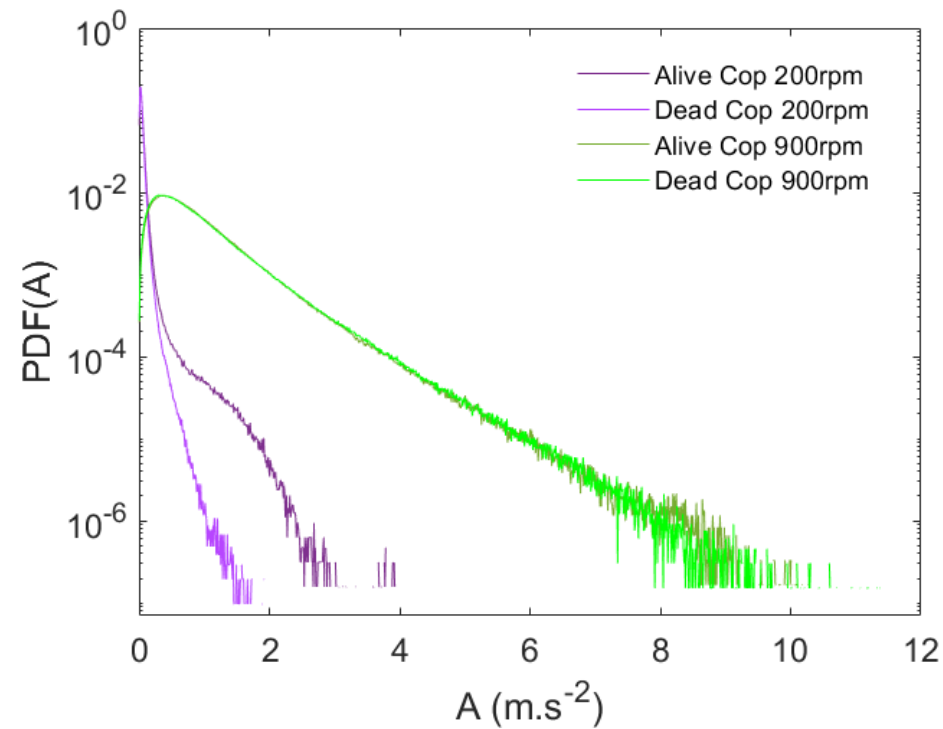
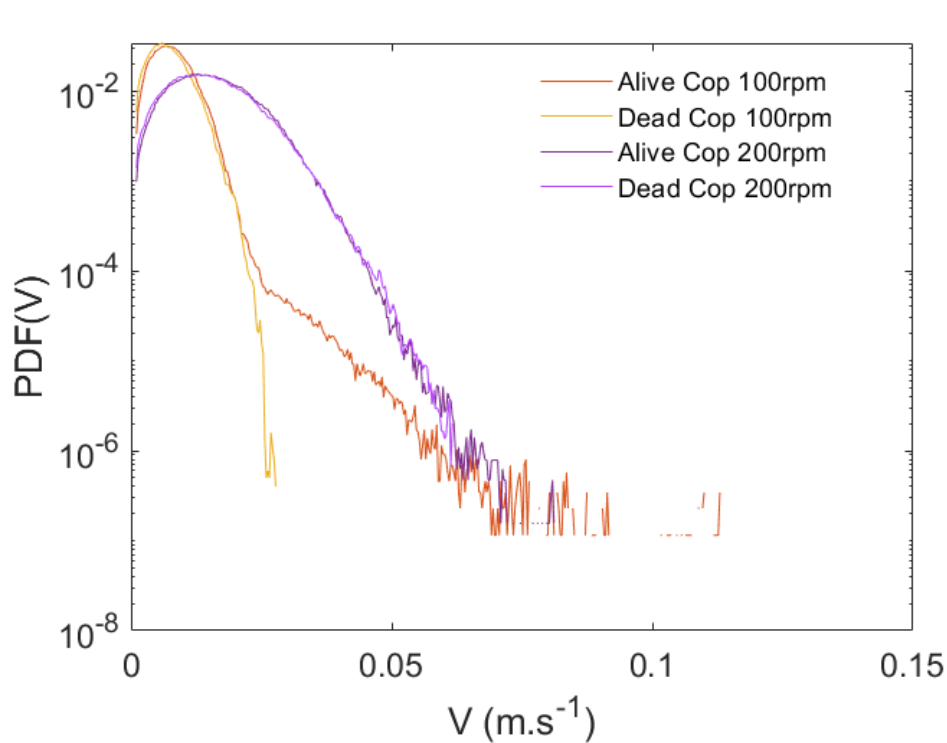
- No differences in average between dead or alive copepods and polystyren particles (error bar : quantile 68%)
- The average value of the velocity modulus (Threshold $V > 1 \text{ mm.s}^{-1}$) at 0 rpm is $4,8 \text{ mm.s}^{-1}$
- The average value of the acceleration modulus at 0 rpm is $0,27 \text{ m.s}^{-2}$

Difference between
Alive and Dead
copepods at low
intensity of
turbulence (100rpm)



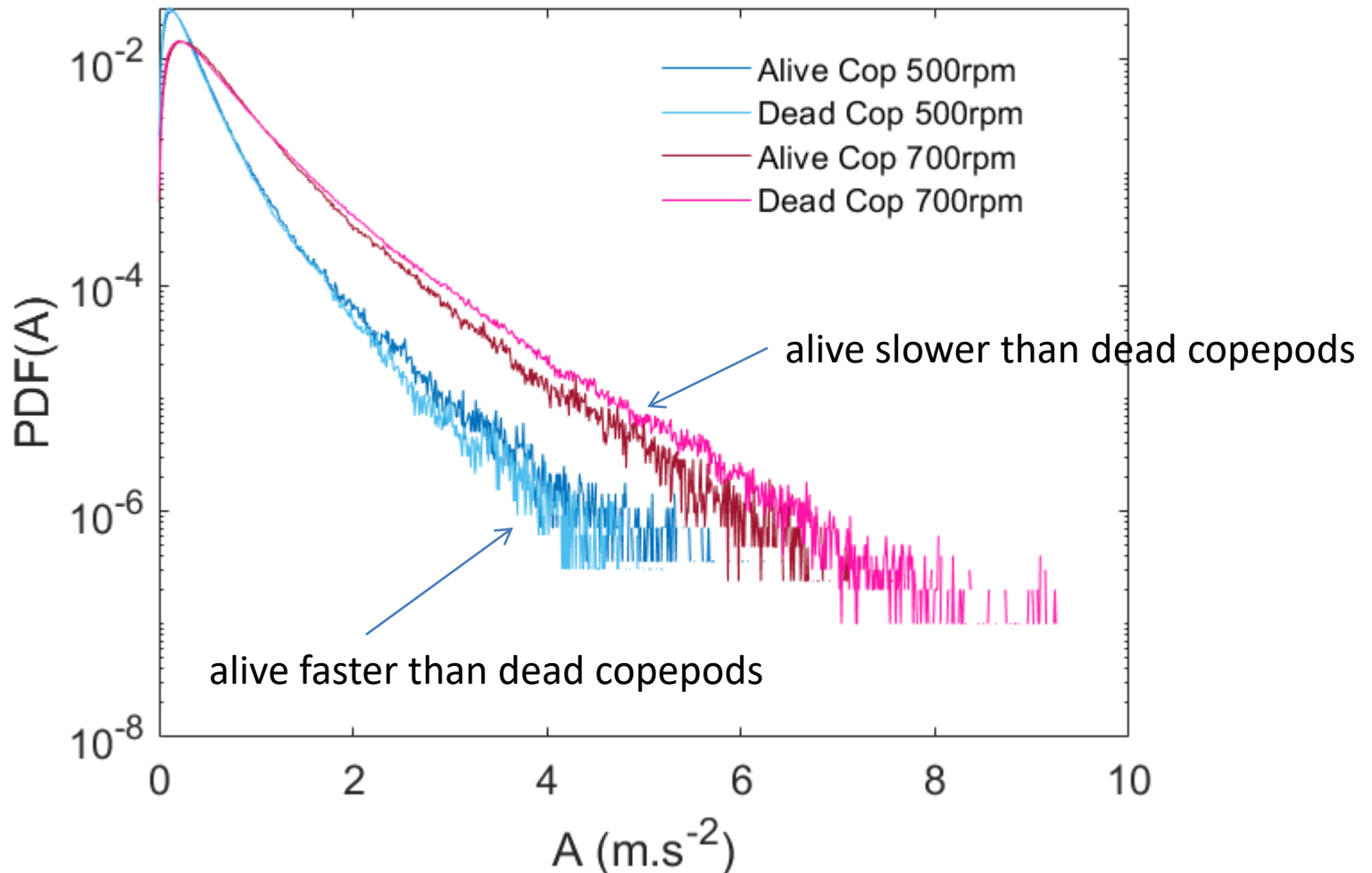
- The velocity modulus at which the difference occurs is 2.57 cm.s⁻¹





- The pdf of the velocity or acceleration modulus gets broader at higher turbulence intensities.
- The difference between alive and dead copepods disappears when the turbulence increases. Signs of swimming behavior are longer visible in the acceleration signal.

Some swimming signs are visible up to 700rpm?



Main messages

- The experimental system generating turbulence is operational. We are characterizing turbulence statistics using particles of different sizes. It is a first system to study experimentally copepods in turbulence with infra-red and high speed cameras
- In a controlled turbulent environment, generated by this newly designed experimental setup, it has been possible to follow copepods behavior at different R_λ .
- Swimming behavior of copepods depends on the turbulence intensity : when turbulence is too high copepods let themselves to be carried by the flow without swimming.
- For a large range of intensities, copepods show some swimming abilities.
- Perspectives : Does the transition occur at the same intensities when copepods are feeding (in presence of phytoplankton)?

Thanks for your attention



Happy to answer to your questions
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