The AGITURB laboratory turbulence generation system and its application to plankton studies: zooplankton and phytoplankton

15 minutes online version of the presentation belonging to the session

NP6.2 Turbulence and plankton

EGU 2022

François G. Schmitt (CNRS, LOG), **Clotilde Le Quiniou** (ULCO, LOG), **Yongxiang Huang** (Xiamen Univ.), **Enrico Calzavarini** (Université de Lille, UML), **Emilie Houliez** (ULCO, LOG), **Urania Christaki** (ULCO, LOG)

cnrs

Université de Lille

ulco Université Littoral Côte d'Opale

LOG Laboratoire d'Océanologie et de Géosciences

EGU General Assembly 2022

The AGITURB laboratory turbulence generation system and its application to plankton studies: zooplankton and phytoplankton

François G. Schmitt (CNRS, LOG), **Clotilde Le Quiniou** (ULCO, LOG), **Yongxiang Huang** (Xiamen Univ.), **Enrico Calzavarini** (Université de Lille, UML), **Emilie Houliez** (ULCO, LOG), **Urania Christaki** (ULCO, LOG)

Université de Lille

Université Littoral Côte d'Opale

LOG Laboratoire d'Océanologie et de Géosciences

EGU General Assembly 2022

Context

Turbulence and marine ecosystems

Turbulence plays a big role in marine ecosystems

Mixing
Transport of particles
Transport dissolved quantities
Contact rates between particles
exchanges through interfaces
Fluxes
…

Context

Turbulence and marine ecosystems

« Almost all flows in nature are turbulent. This type of flow is of extraordinary meaning for all aquatic life, since without turbulence such habitat could not be conceivable. » (Ambühl 1959)

« There is no life without water, and there is no life in water without turbulence. » (Margalef, 1997)

Context

Turbulence and plankton

Plankton lives in suspension in water. It is fully adapted to its turbulent environment through thousands or millions of generations.

Lagrangian transport.

Diffusion of oxygen, of particles, of dissolved quantities

Zooplankton:

- contact rate (reproduction, food)
- transport

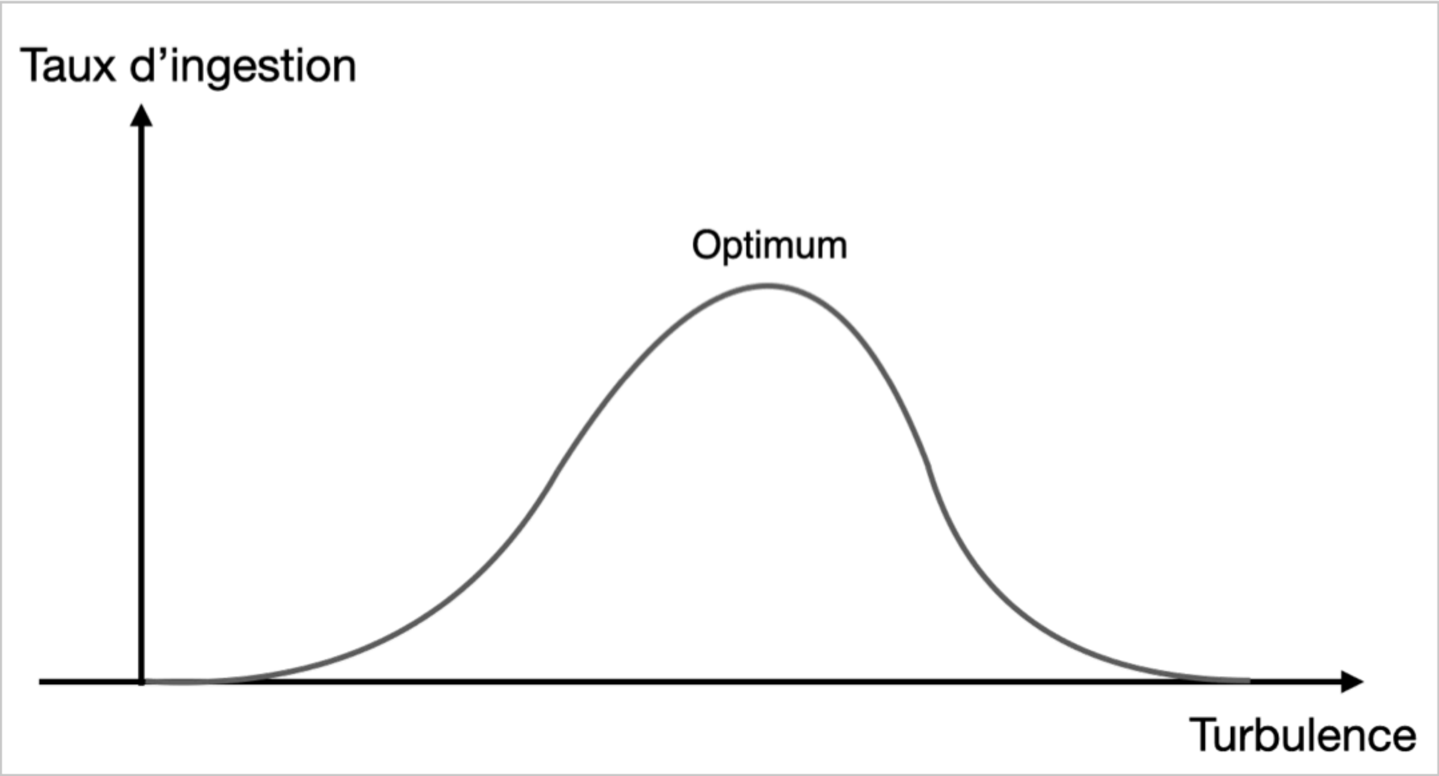
Phytoplankton:

- diffusion of nutrients (food)
- transport, especially along the vertical

Copepods in turbulence

- Copepods are small crustaceans (~300 μm to 1 mm)
- Many copepod species have swimming activities: slow swimming and jumps (~40 cm/s; ~10 G)
- They are adapted to their turbulent environment
- There is an increase of the encounter rate due to turbulence
- But too much turbulence may inhibit the ingestion rate: this is the so-called « **dome-shape** »

- **Question**: how do their swimming activity depends on the local turbulence?
- **Methodology**: laboratory study, construction of a system to generate turbulence. Use of high speed cameras.



Context

Three approaches in the geosciences

$$\frac{\partial u_x}{\partial t} + u_x\frac{\partial u_x}{\partial x} + u_y\frac{\partial u_x}{\partial y} + u_z\frac{\partial u_x}{\partial z} = -\frac{\partial p}{\partial x} + \nu\left(\frac{\partial^2 u_x}{\partial x^2} + \frac{\partial^2 u_x}{\partial y^2} + \frac{\partial^2 u_x}{\partial z^2}\right)$$

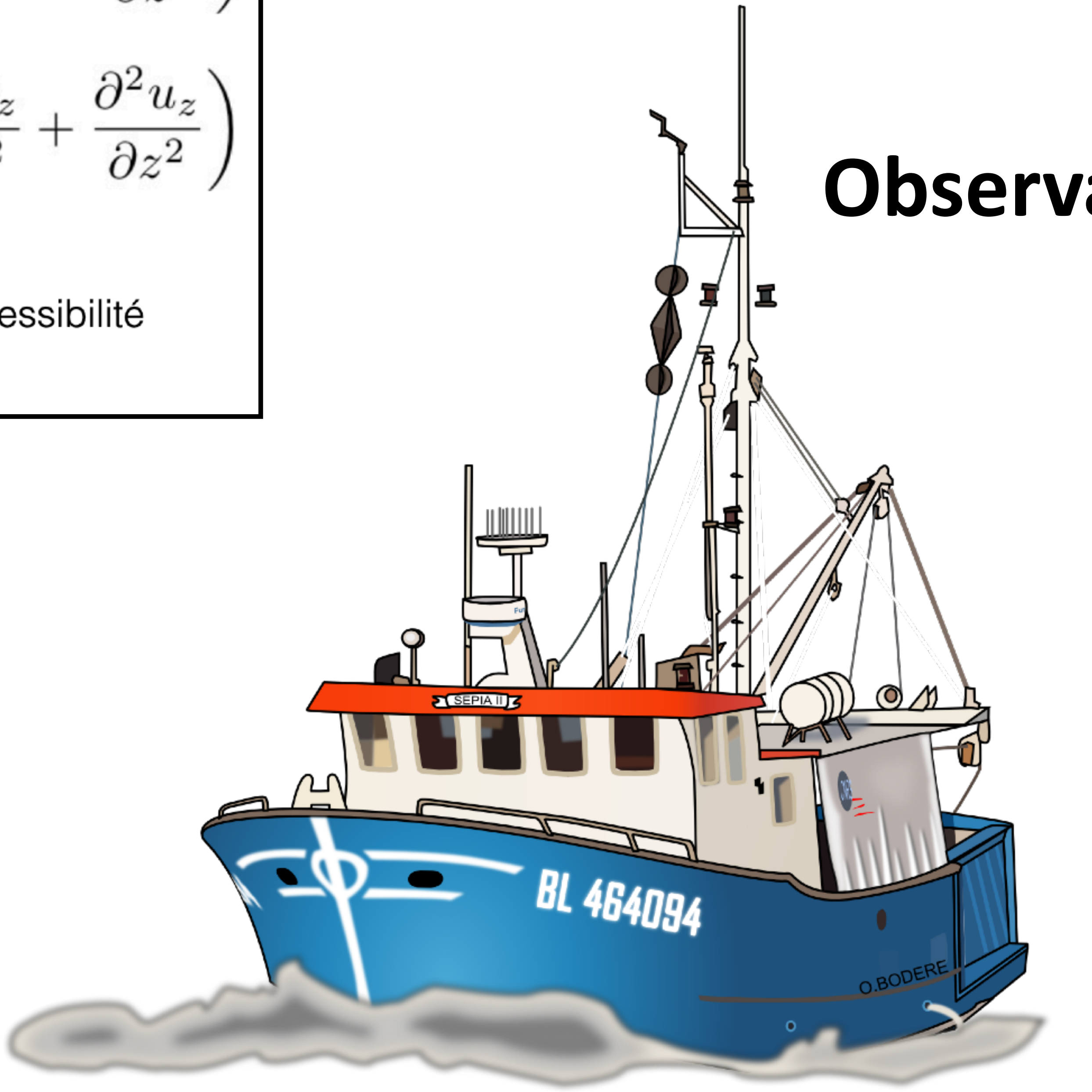
$$\frac{\partial u_y}{\partial t} + u_x\frac{\partial u_y}{\partial x} + u_y\frac{\partial u_y}{\partial y} + u_z\frac{\partial u_y}{\partial z} = -\frac{\partial p}{\partial y} + \nu\left(\frac{\partial^2 u_y}{\partial x^2} + \frac{\partial^2 u_y}{\partial y^2} + \frac{\partial^2 u_y}{\partial z^2}\right)$$

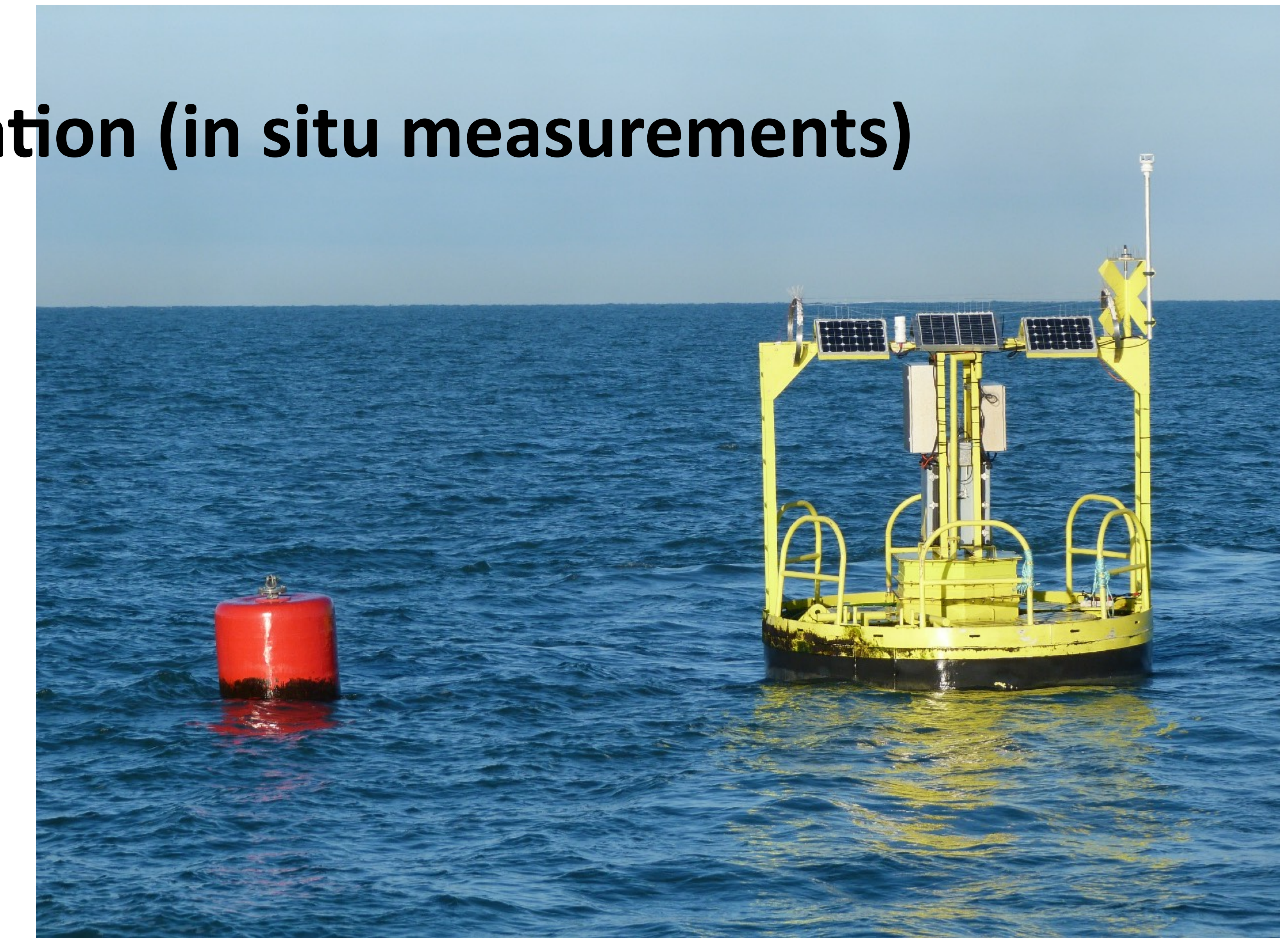
$$\frac{\partial u_z}{\partial t} + u_x\frac{\partial u_z}{\partial x} + u_y\frac{\partial u_z}{\partial y} + u_z\frac{\partial u_z}{\partial z} = -\frac{\partial p}{\partial z} + \nu\left(\frac{\partial^2 u_z}{\partial x^2} + \frac{\partial^2 u_z}{\partial y^2} + \frac{\partial^2 u_z}{\partial z^2}\right)$$

$$\frac{\partial u_x}{\partial x} + \frac{\partial u_y}{\partial y} + \frac{\partial u_z}{\partial z} = 0$$ Incompressibilité

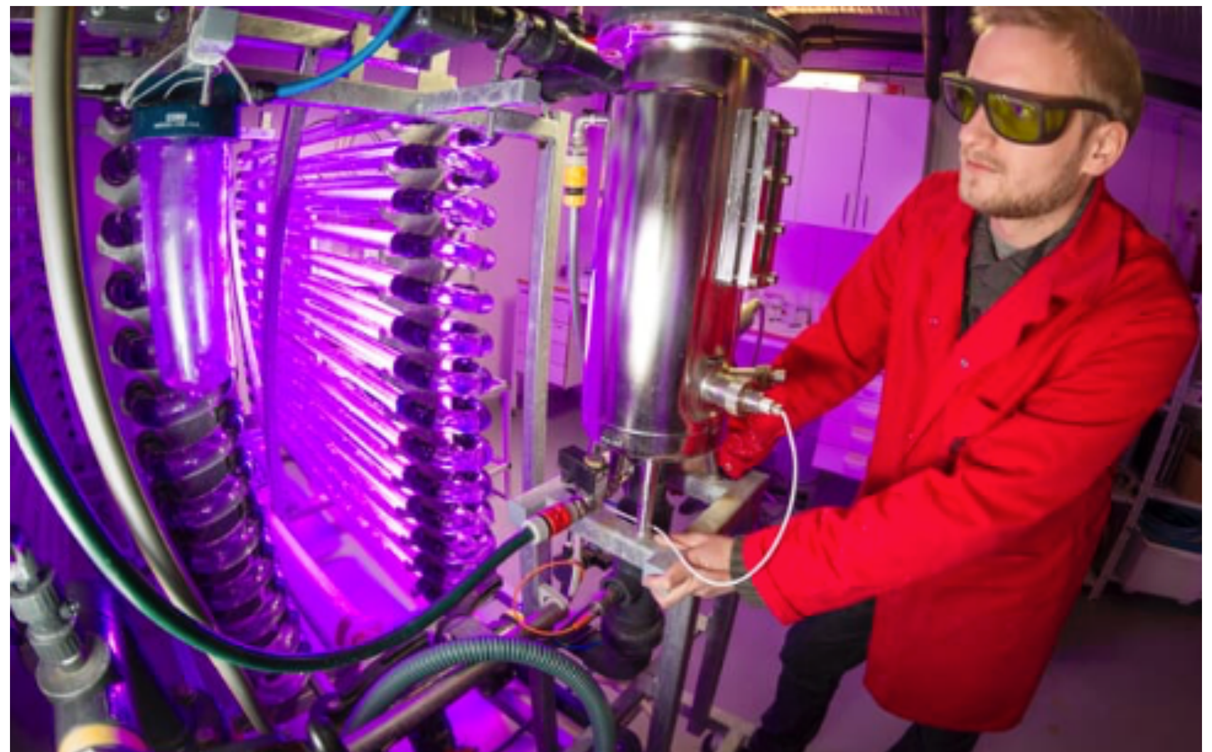
Theories and models

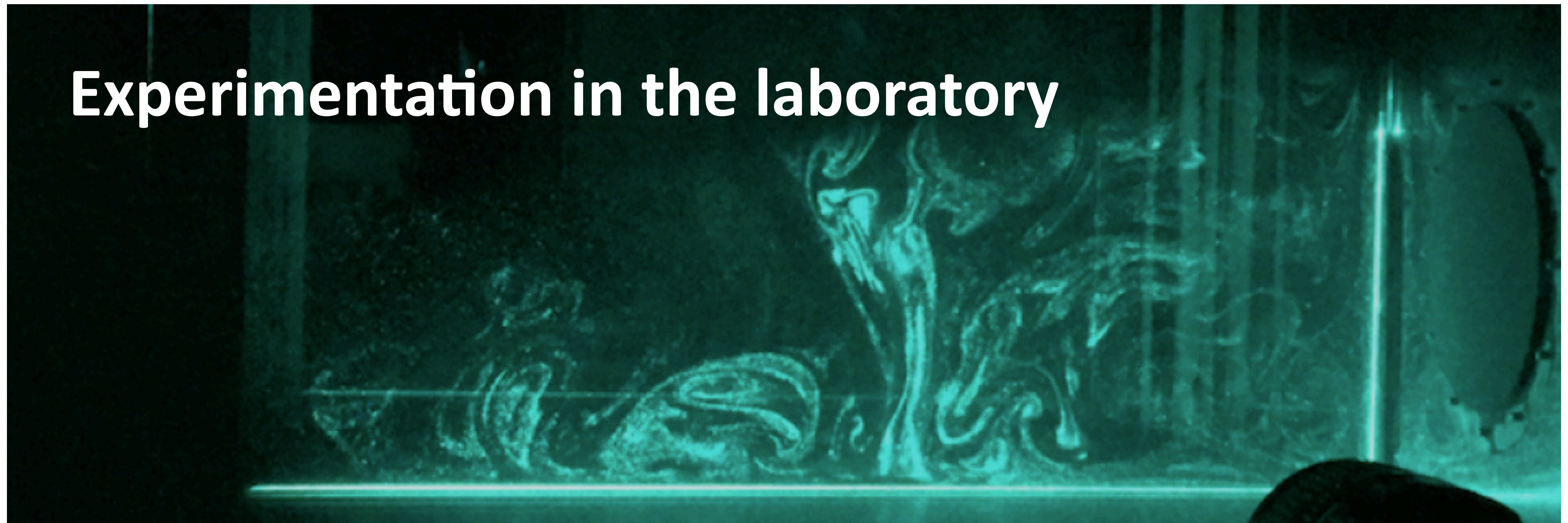
Observation (in situ measurements)





Experimentation in the laboratory



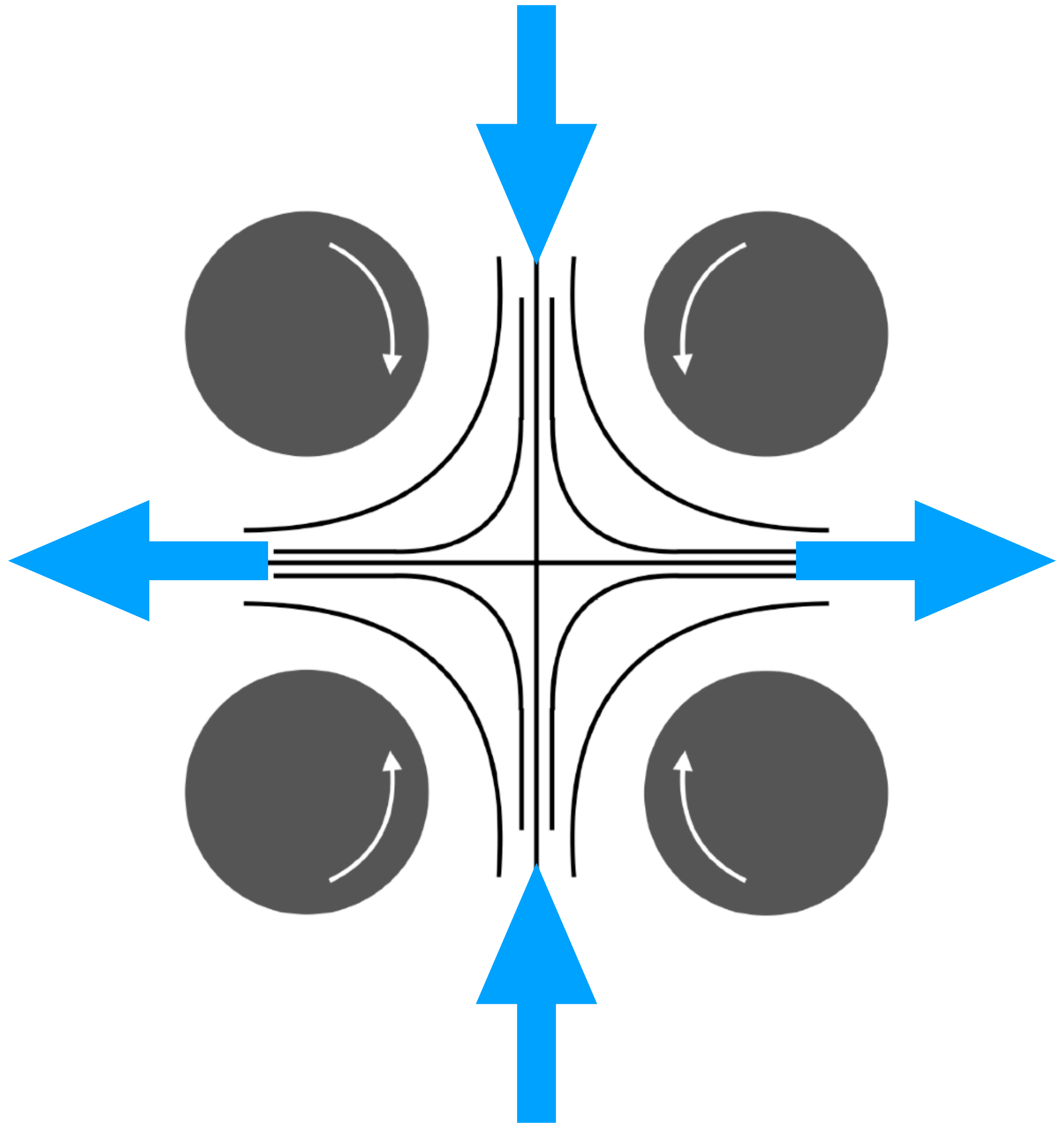


AGITURB

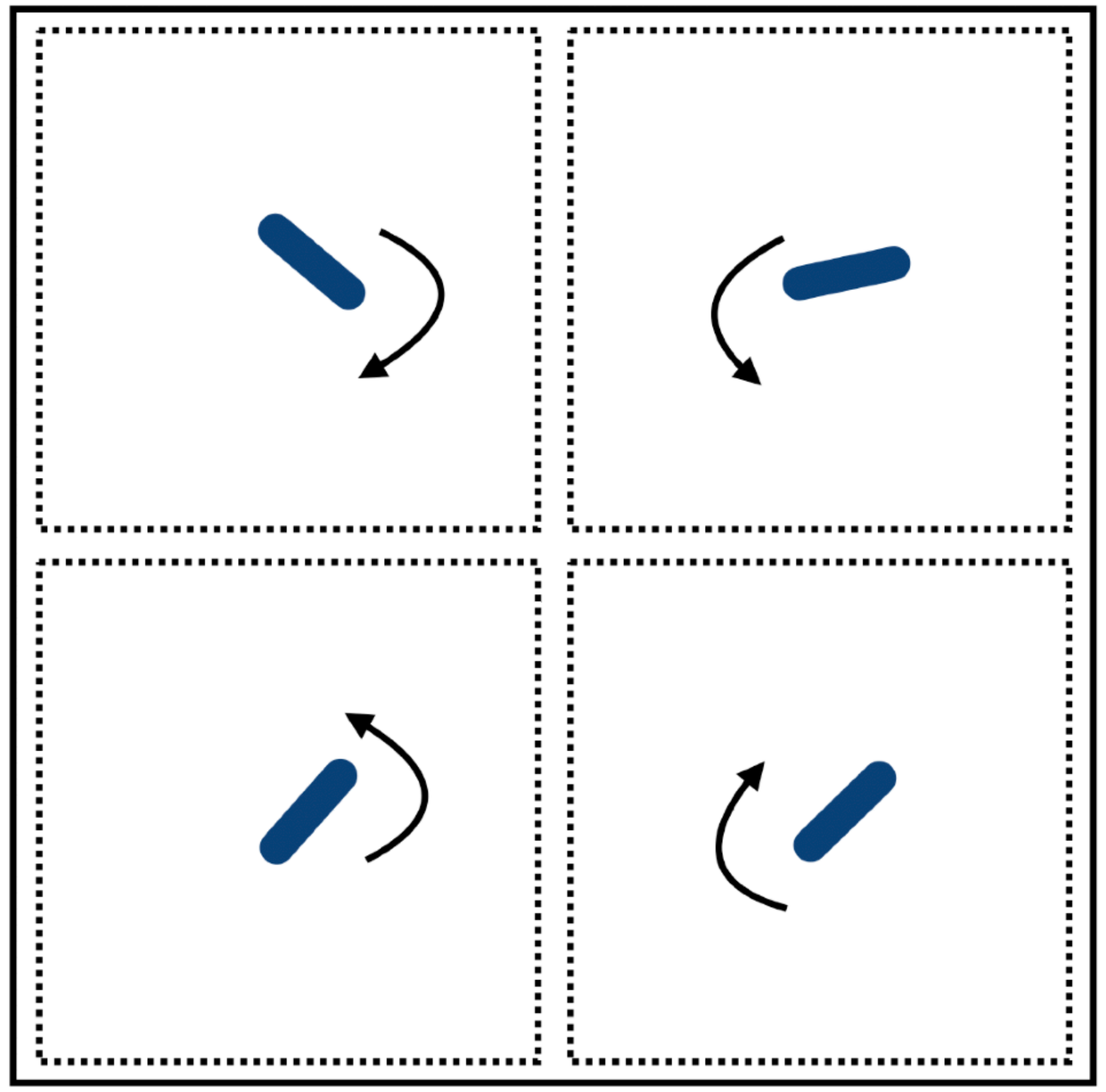
Work of Clotilde Le Quiniou
(post-doc)

« AGITURB »,
a new system to generate controlled turbulence in the lab

« Four-roll mill »
(Taylor, 1934)



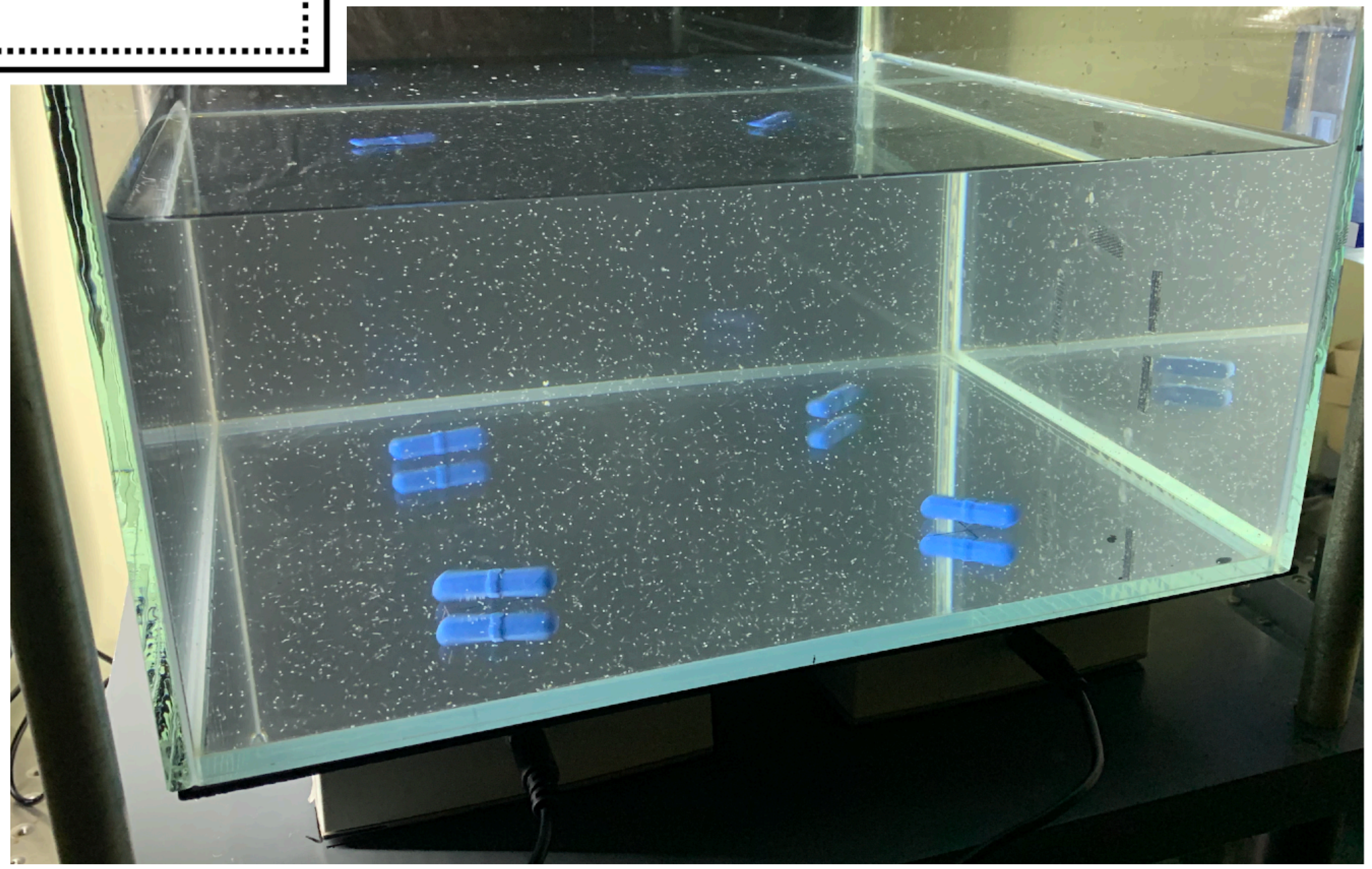
a laminar strain-dominated two-dimensional flow
four rolls having contra-rotating rotation rates



« AGITURB »

free flow similar to four-roll mill

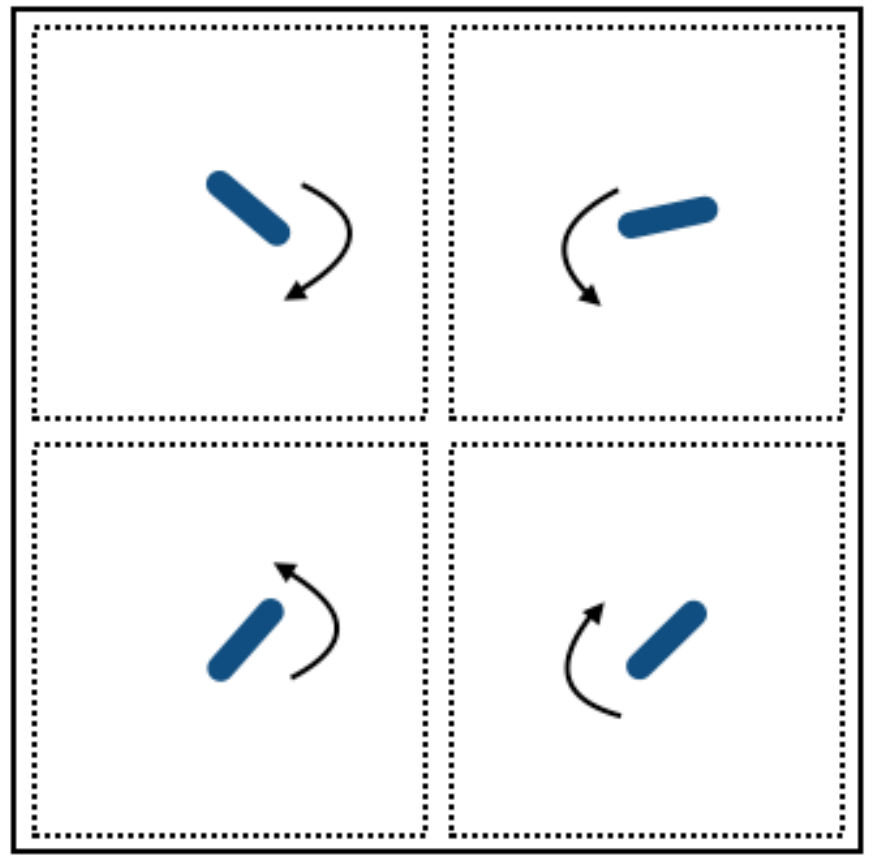
4 stirring bars activated by magnetic stirrers, contratotating, situated under the tank



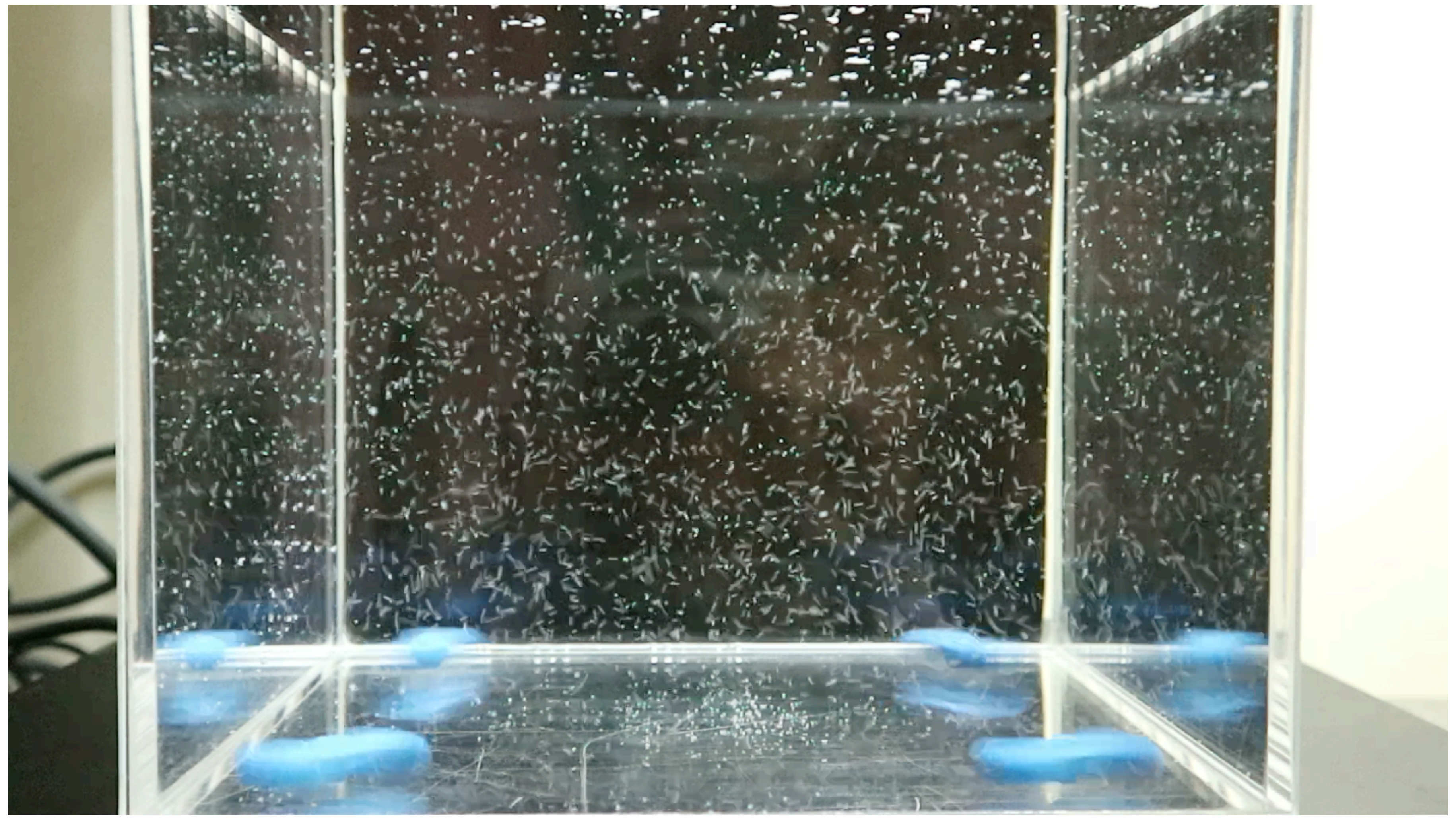
AGITURB

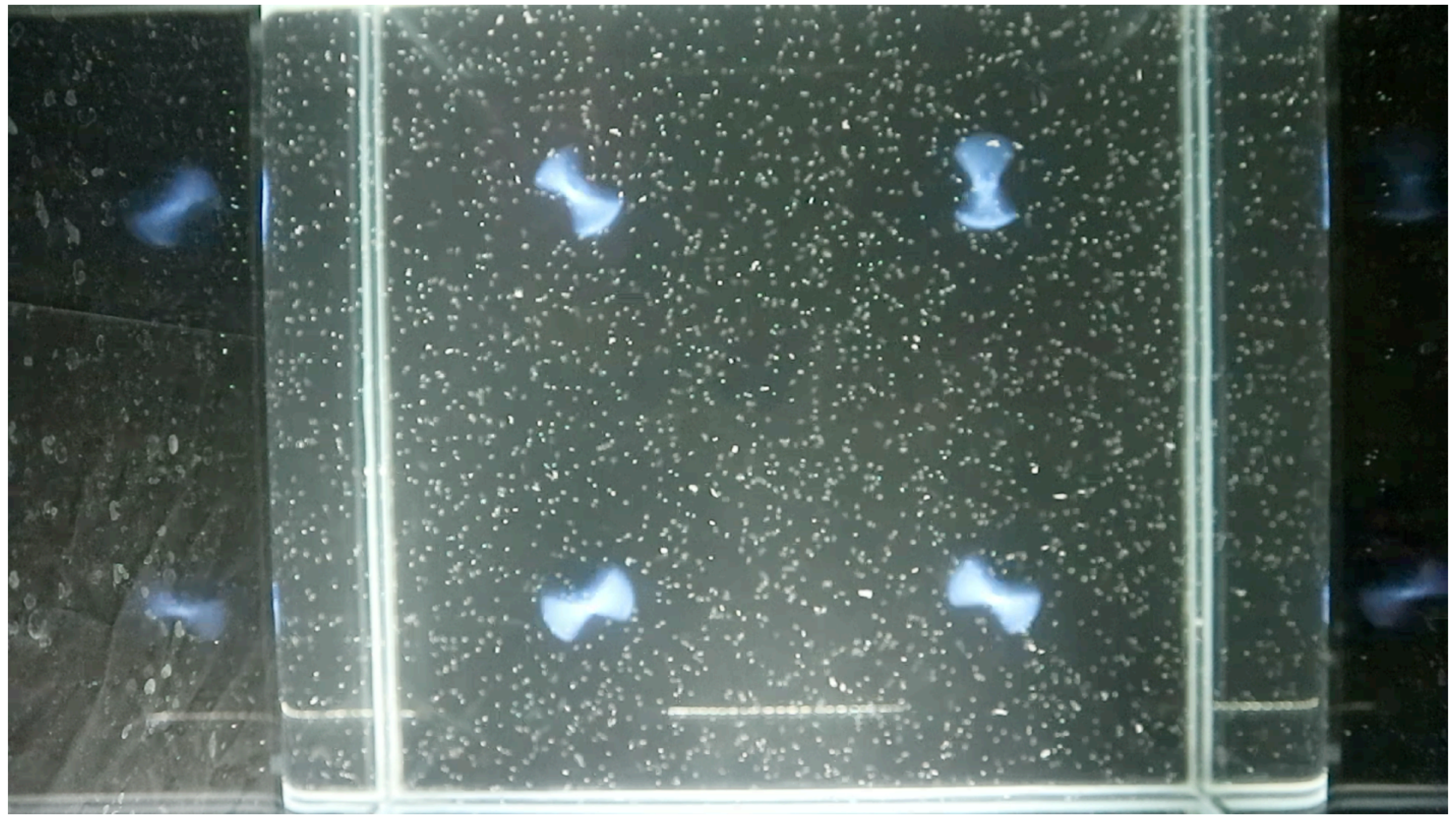
« AGITURB »,
a new system to generate controlled turbulence in the lab

Work of Clotilde Le Quiniou
(post-doc)



« AGITURB »

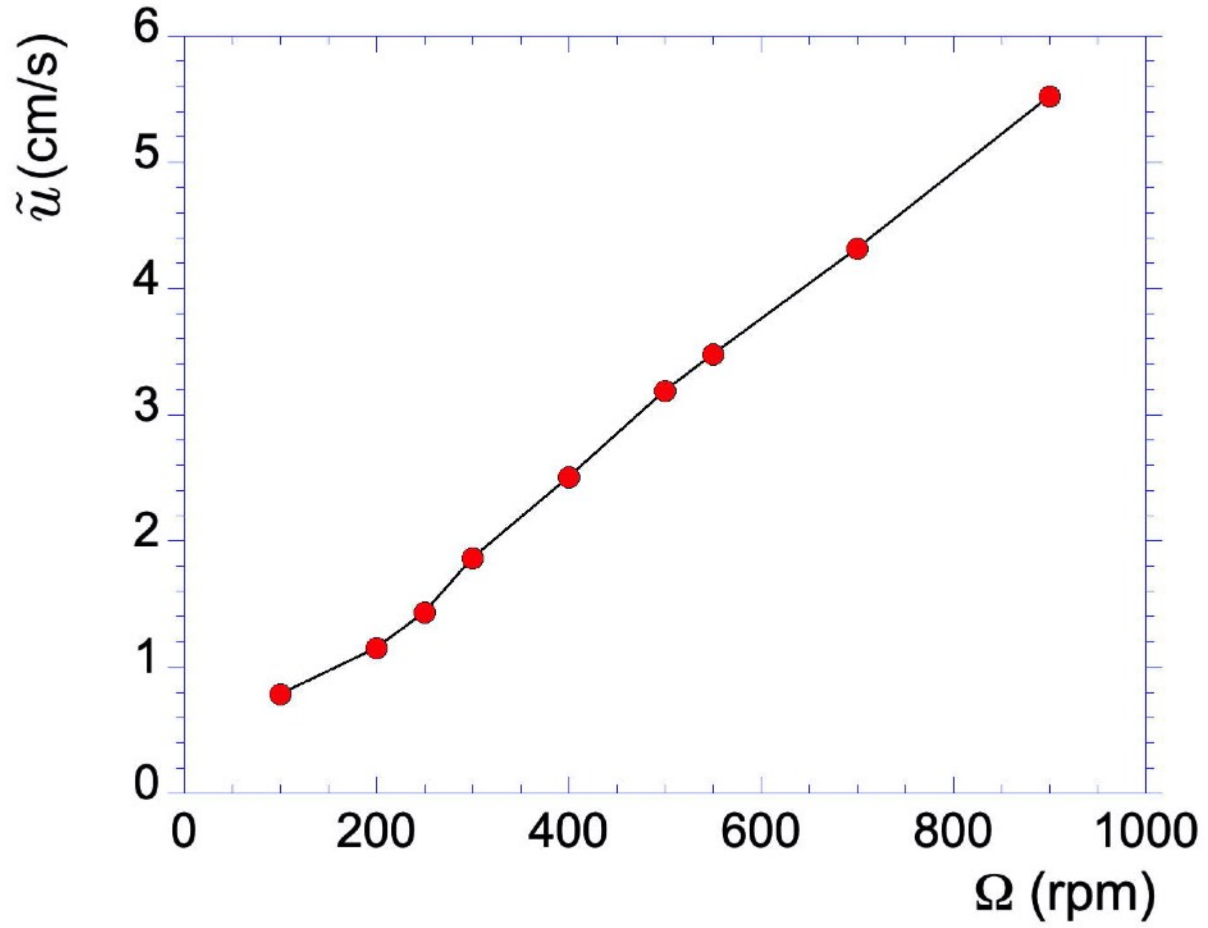




Here with particles (⌀ 600 μm)

Mean velocity fluctuations over the measured zone:

$$\widetilde{u} = \sigma_u = \sqrt{(u - \bar{u})^2}$$



Characterization of the flow

- Kinetic energy $K = \frac{1}{2}\left(\sigma_u^2 + \sigma_v^2 + \sigma_w^2\right)$

$$\tilde{u}^2 = \frac{2}{3}K$$

- Dissipation of kinetic energy ϵ

$$\epsilon = \frac{\tilde{u}^3}{L}$$

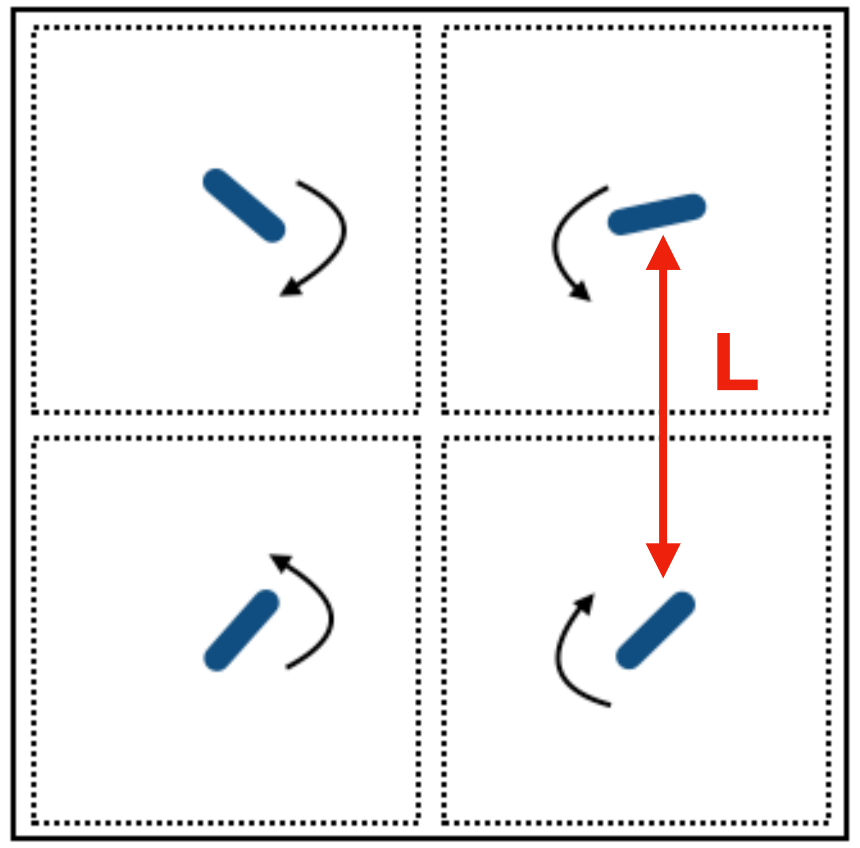
- Kolmogorov scale η

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

- Microscale Reynolds number R_λ

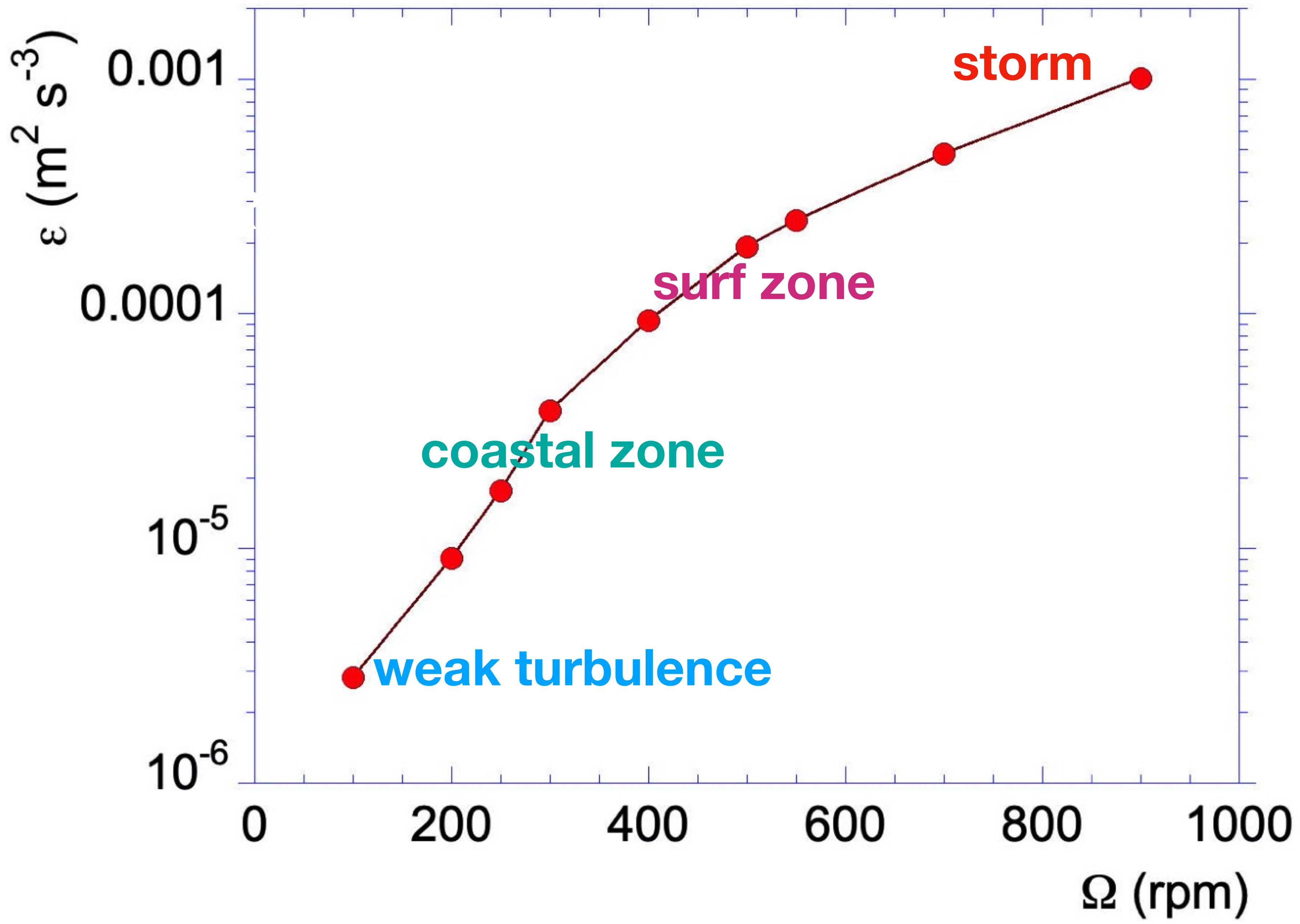
$$\lambda = \sqrt{15}\eta^{2/3}L^{1/3}$$

$$R_\lambda = \frac{\tilde{u}\lambda}{\nu}$$



injection scale

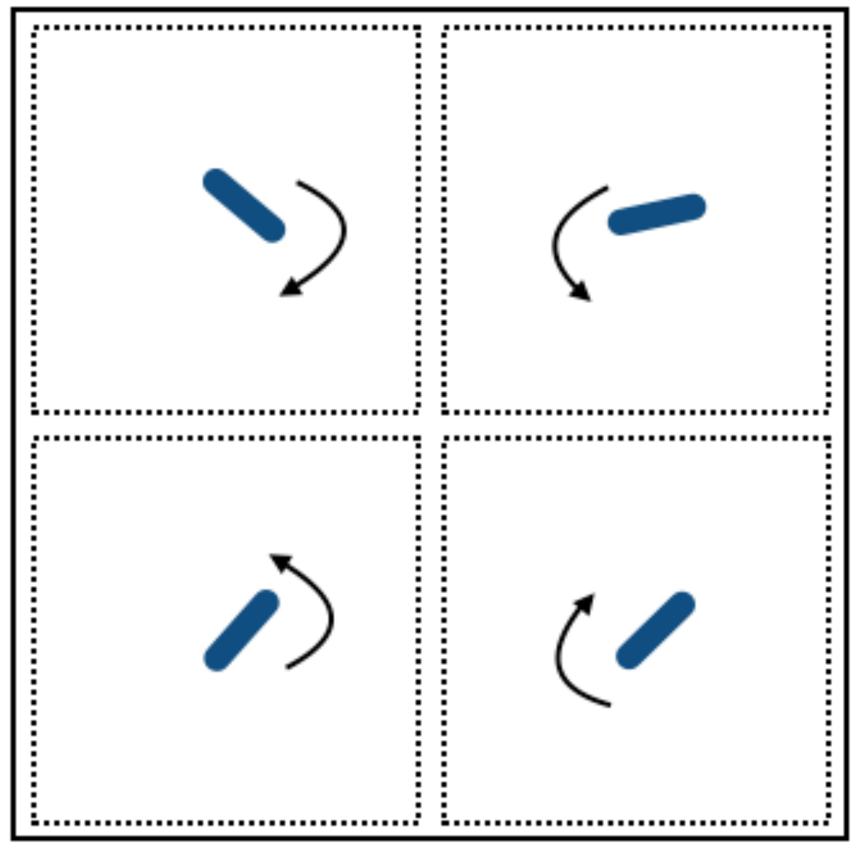
ϵ: between 3×10^{-6} and $10^{-3}\, m^2 s^{-3}$



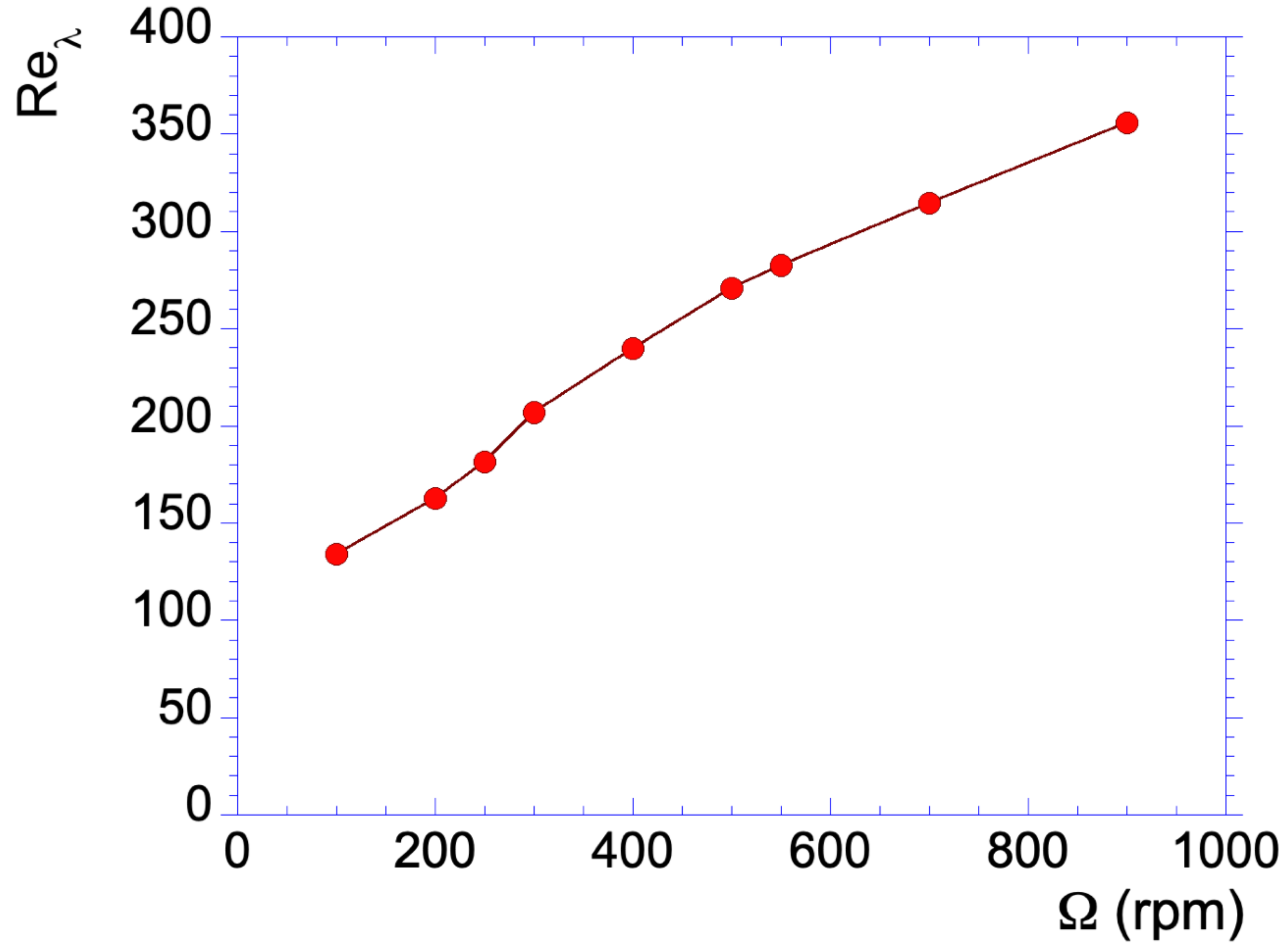
AGITURB

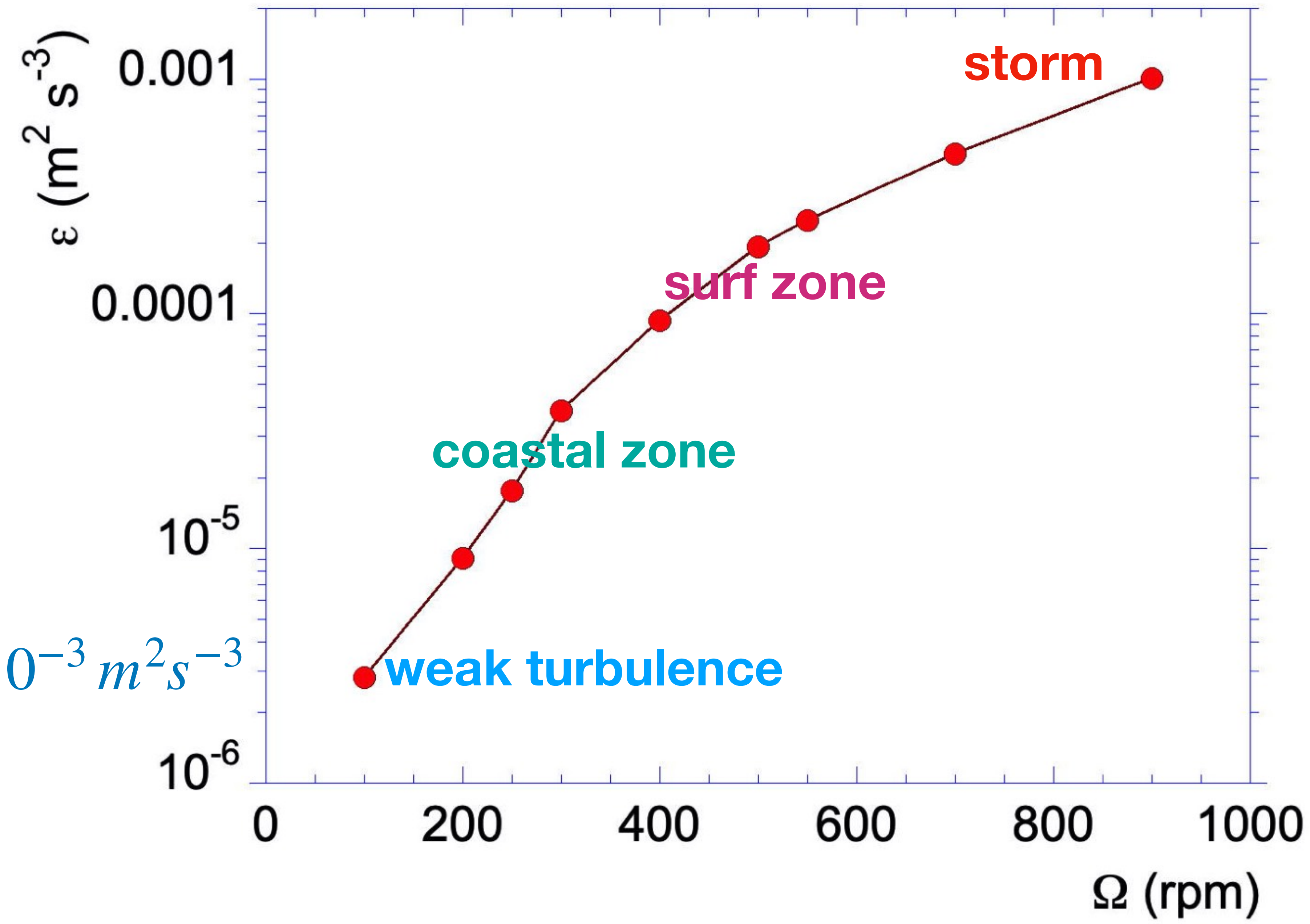
Characterization of the flow

Work of Clotilde Le Quiniou (post-doc)



- Kinetic energy $K = \frac{1}{2}\left(\sigma_u^2 + \sigma_v^2 + \sigma_w^2\right)$
- Dissipation of kinetic energy ϵ $\qquad \epsilon = \frac{\tilde{u}^3}{L}$
- Kolmogorov scale η
- Microscale Reynolds number R_λ $\qquad R_\lambda = \frac{\tilde{u}\lambda}{\nu}$

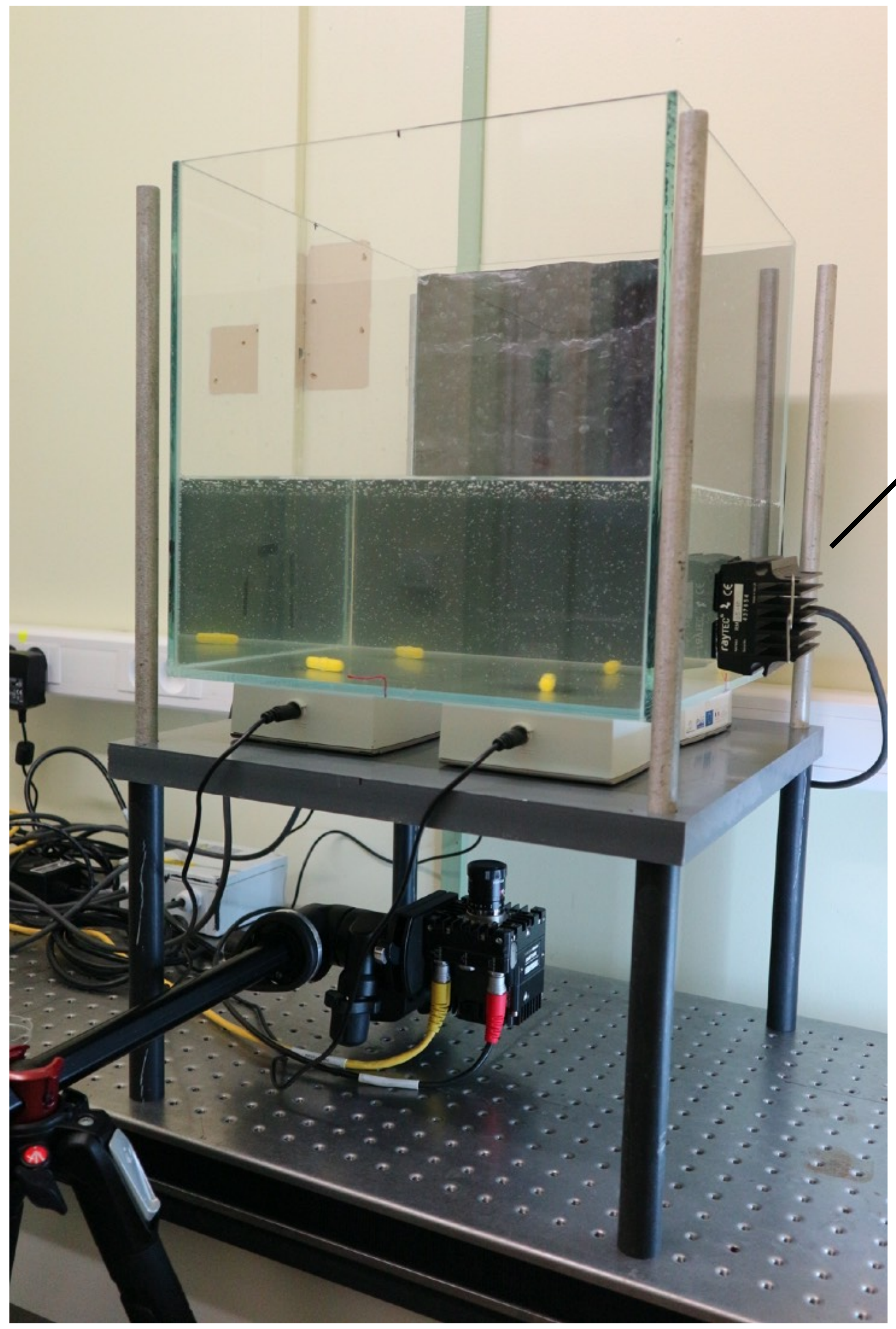




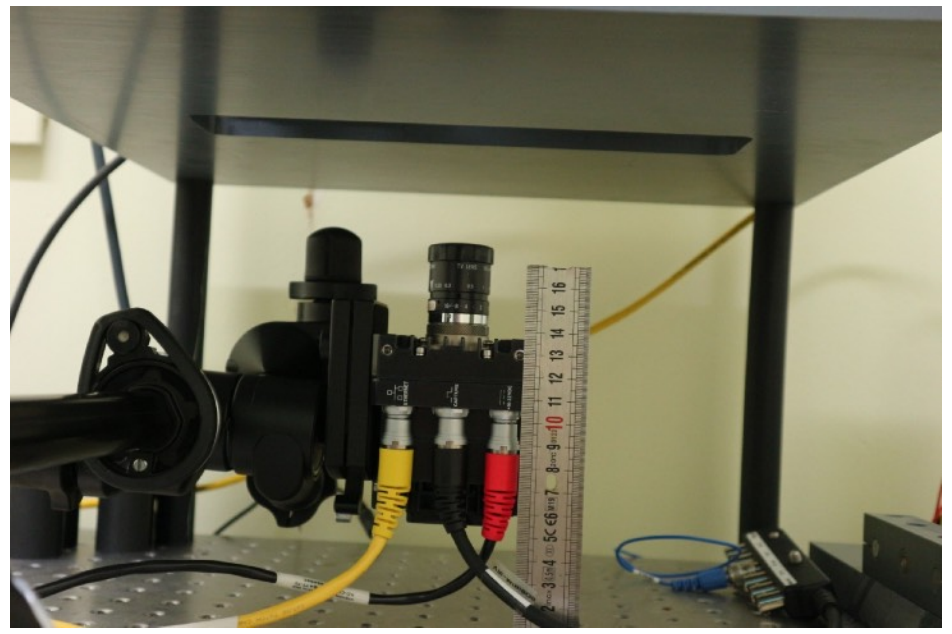
ϵ: between 3×10^{-6} and $10^{-3}\ m^2 s^{-3}$

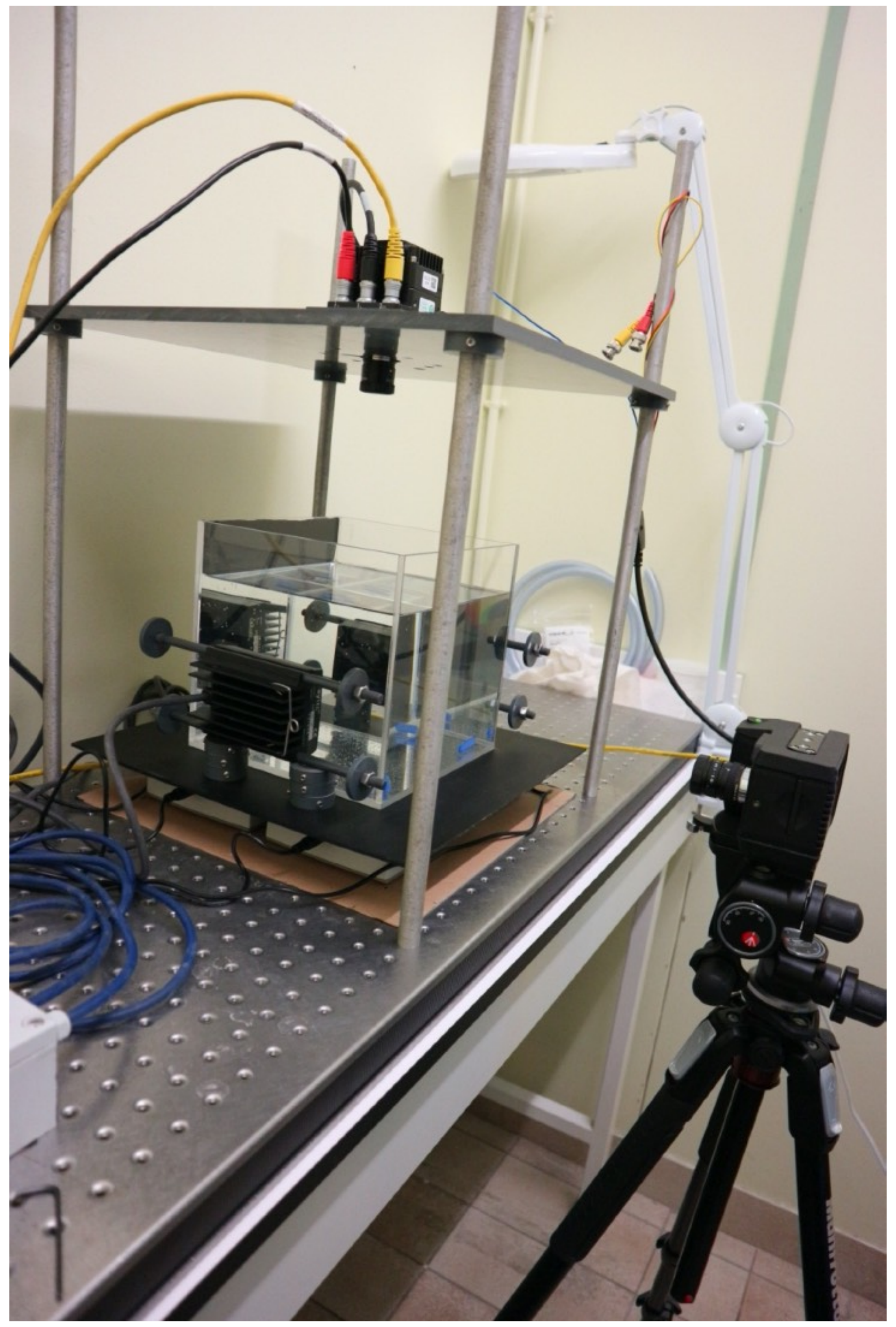
Rotation (RPM)	R_λ	Dissipation	Turbulence	Zone
100	130	3 10^{-6}	Weak	Epicontinental
200	160	10^{-5}	Calm	Coastal zone
400	240	10^{-4}	Agitated	Surf zone
900	360	10^{-3}	Strong	Storm

AGITURB and copepods

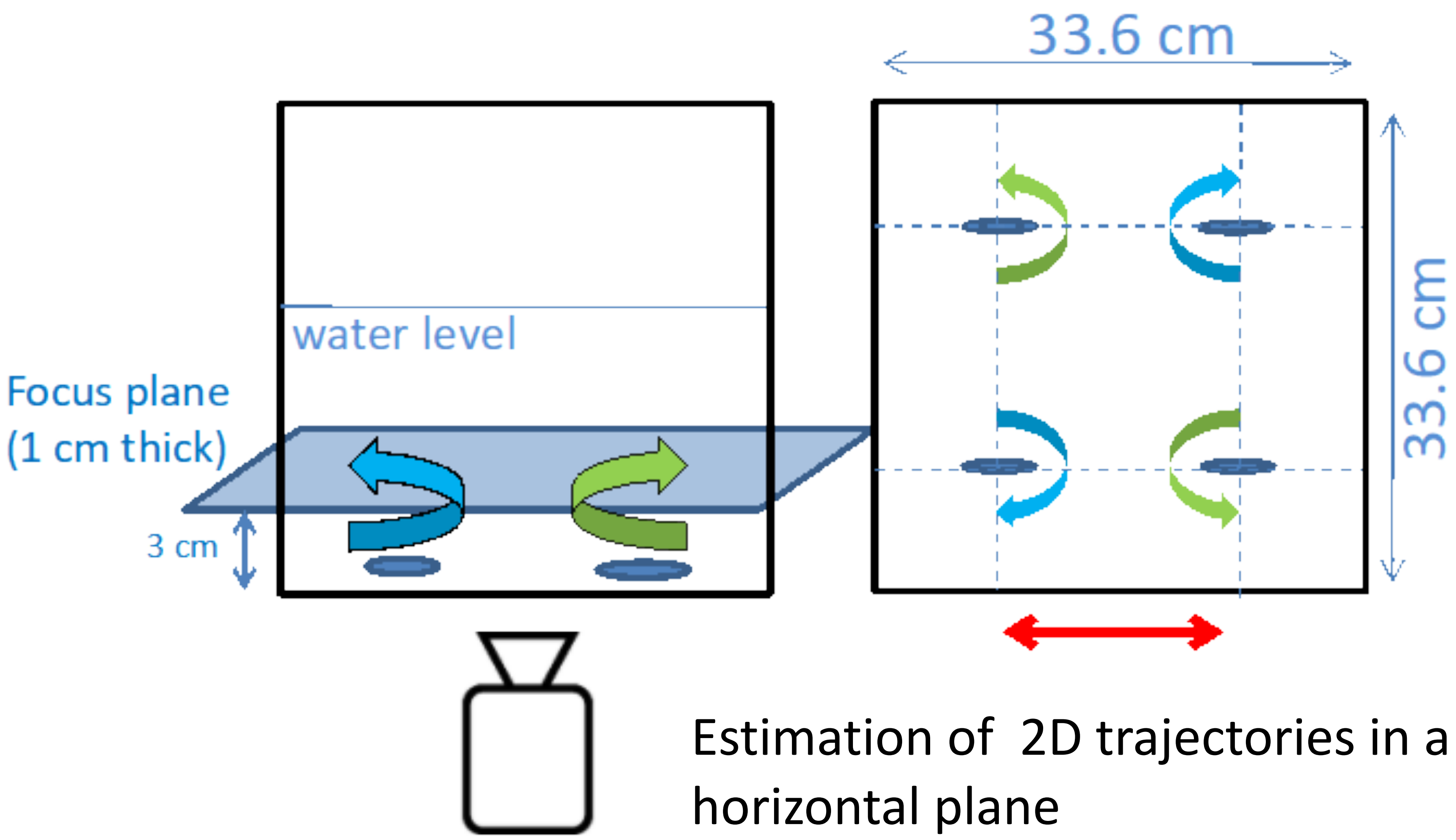


Infrared lamps





- With different rotation rates, different turbulence intensities representative of the field
- Infrared lamps (to avoid phototropism of copepods)
- Extraction of trajectories using a high speed camera (Phantom Miro, 1200 fps)
- Estimation of 2D trajectories in a horizontal plane
- Estimation of velocity and acceleration time series using a kernel smoothing (~60 000 copepods used; 15 To memory)

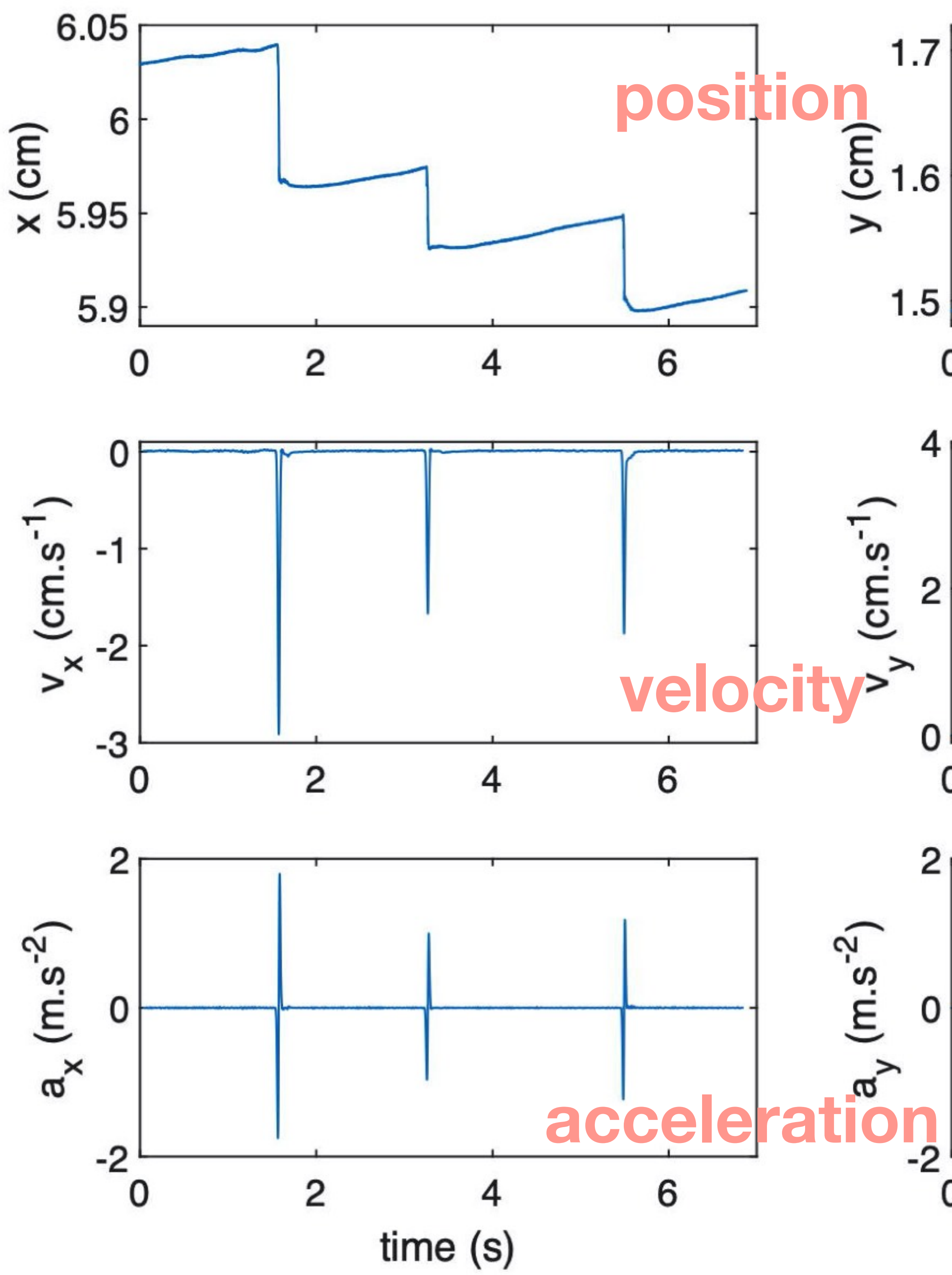


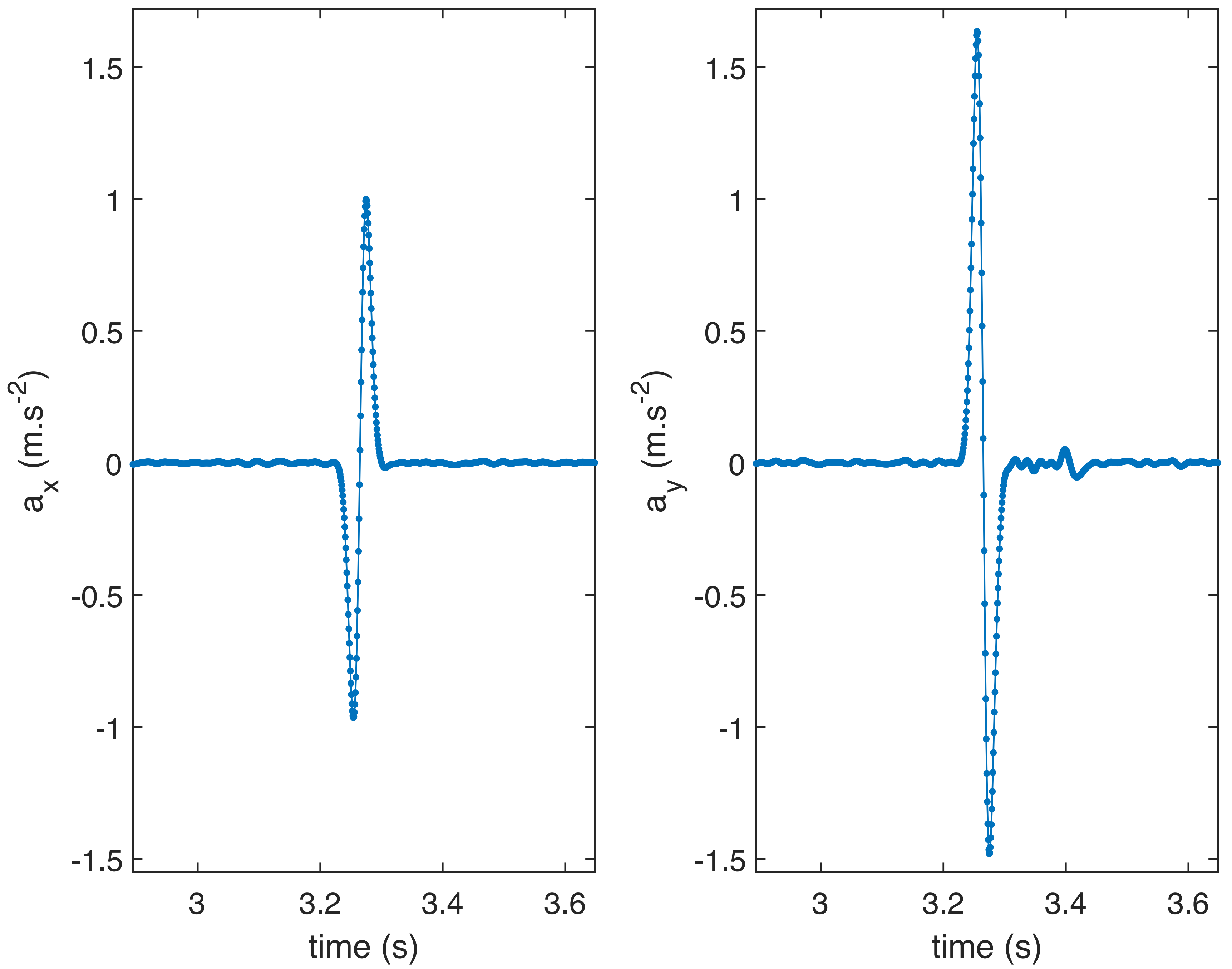
Estimation of 2D trajectories in a horizontal plane

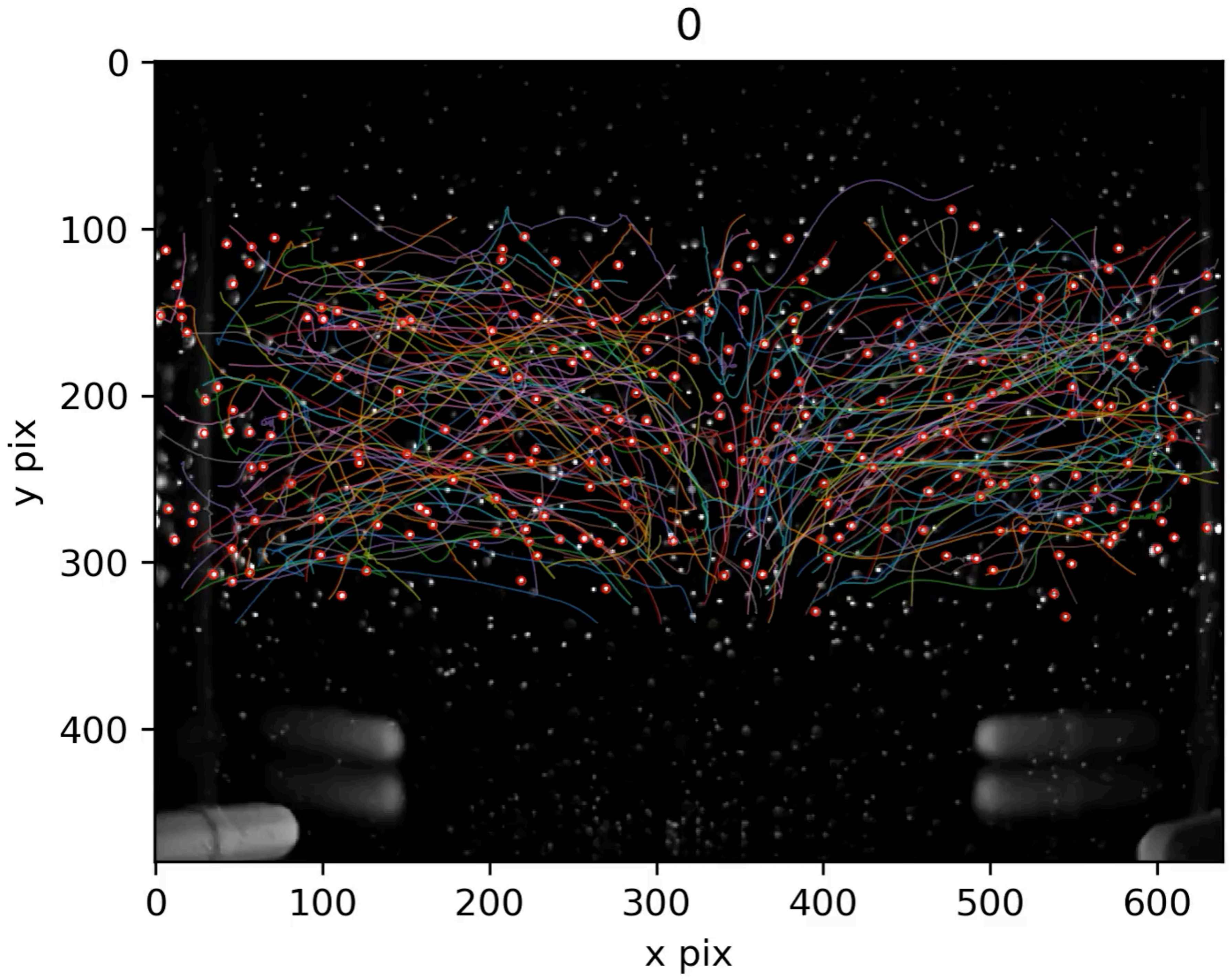
Mass culture of copepods (Sami Souissi)

Extraction of trajectories

zoom on 3 successive jumps



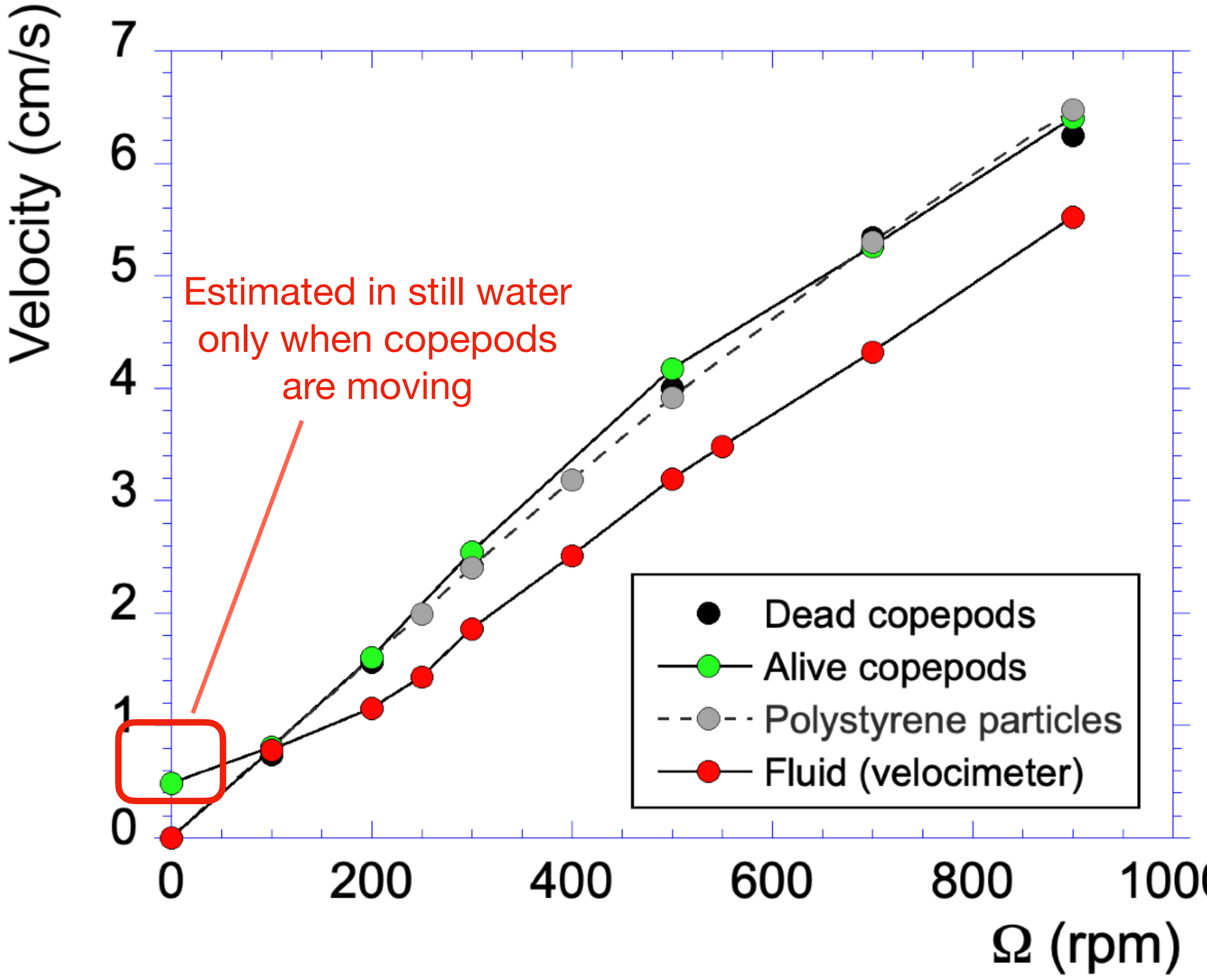




- IR lamps
- High speed camera 1200 fps
- Extraction of collective trajectories
- Estimation of velocity and acceleration of particles and copepods (convolution with a kernel to smooth and extract derivatives at the same time)
- Statistical analyses (averages, pdf, …)

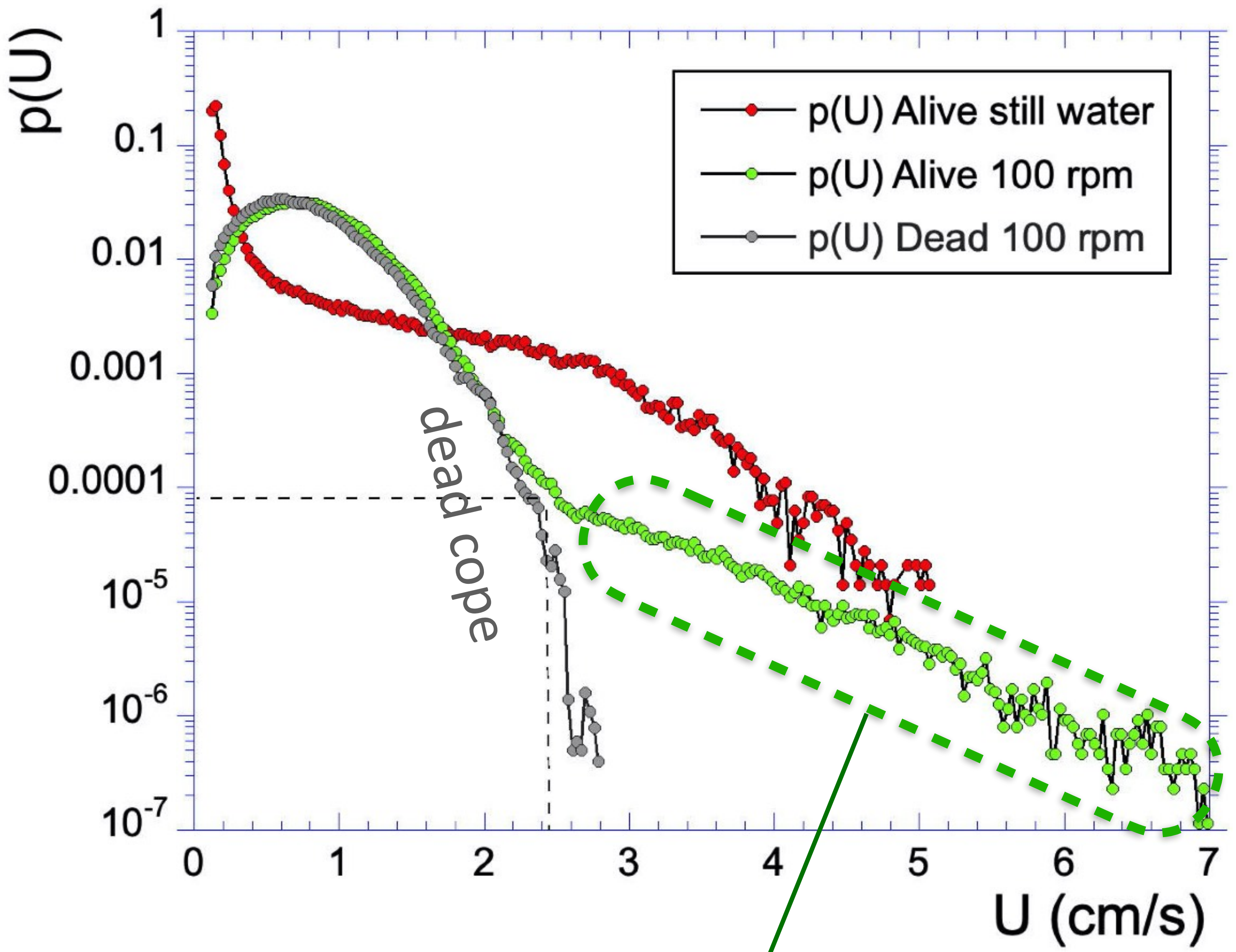
Results: velocity

- Comparison between copepods and polystyrene particles of the same size
- Comparison of dead and alive copepods: show if there is a swimming behavior
- Done for different turbulence levels



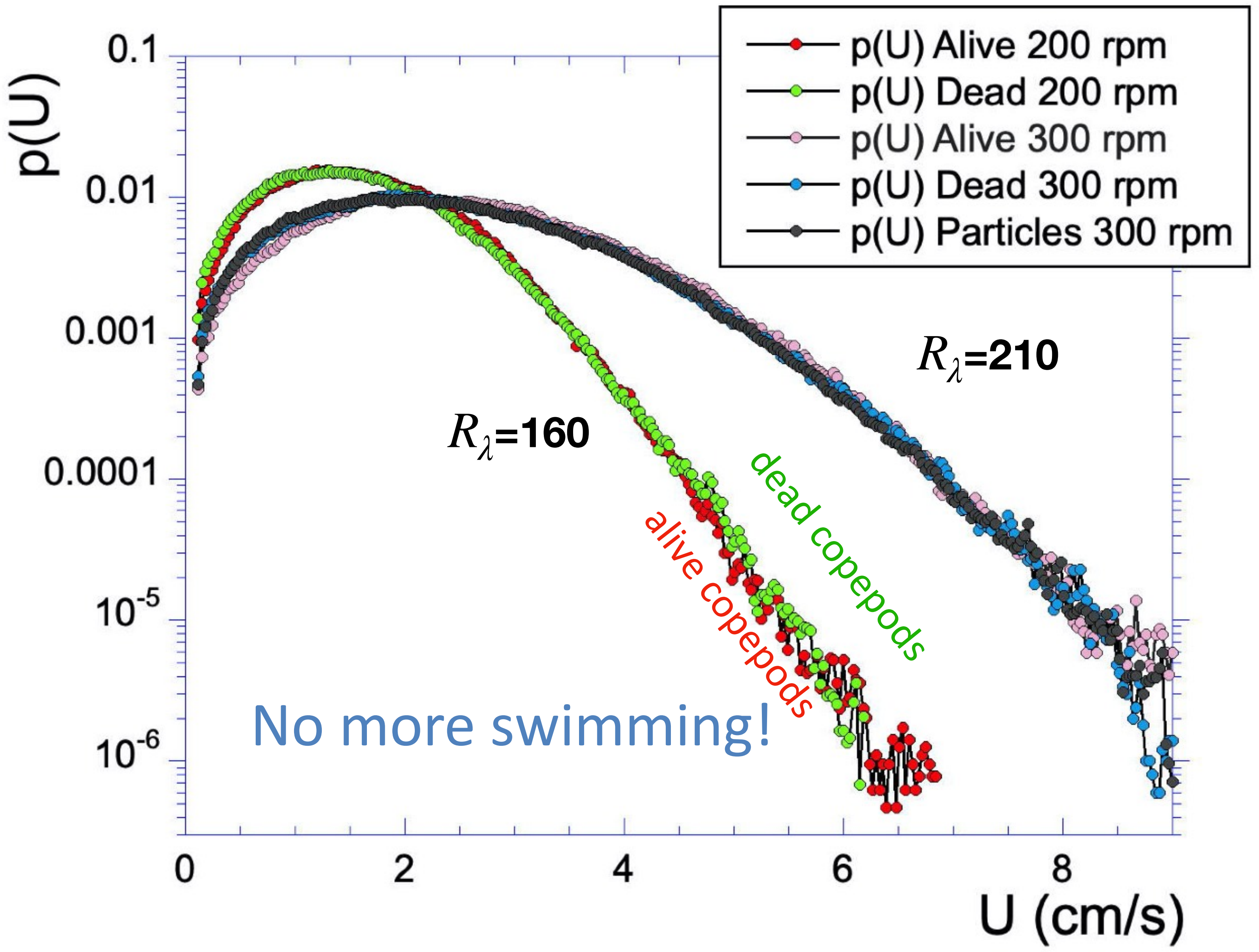
Mean velocities: no visible difference

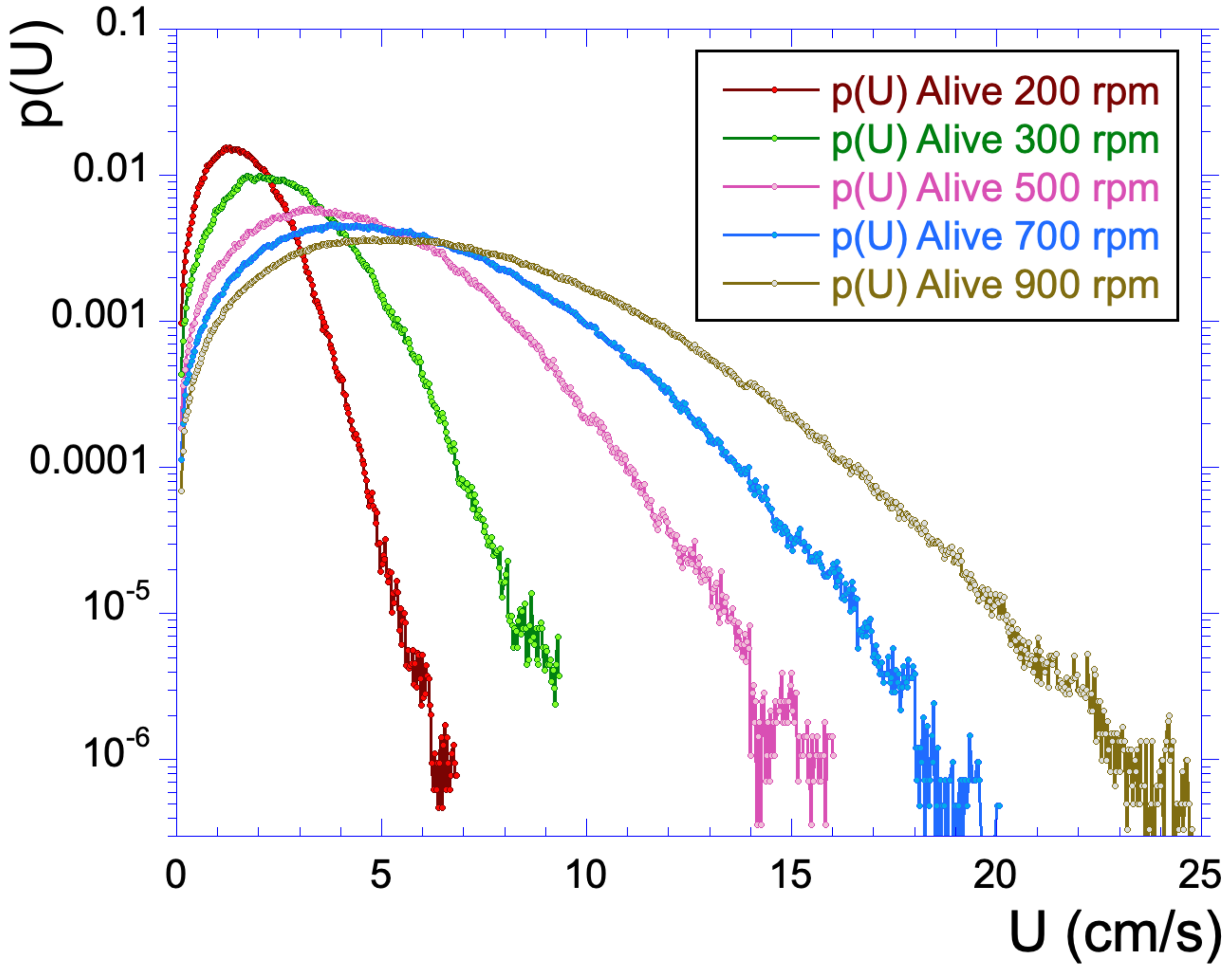
R_λ=130



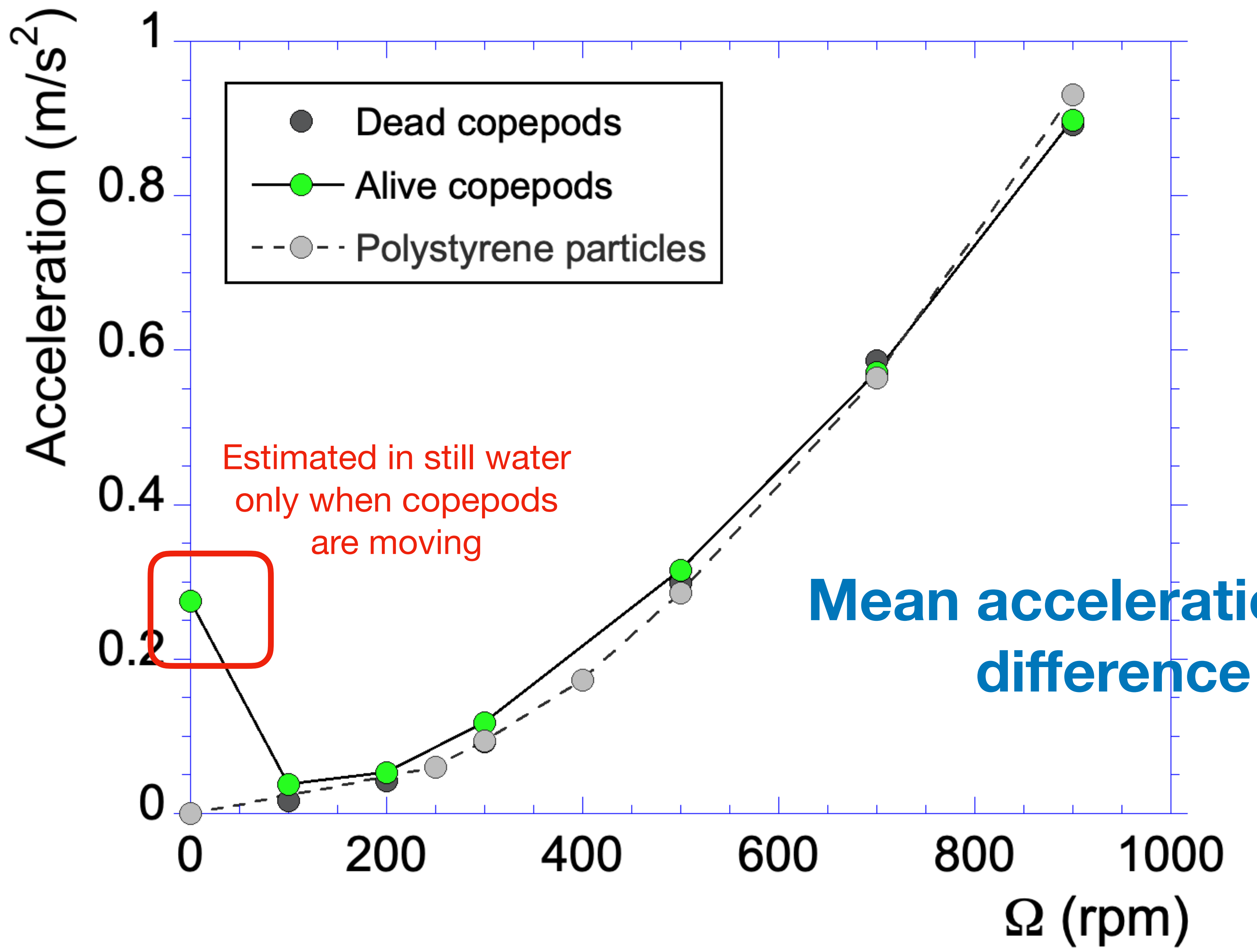
Indicates swimming activities of alive copepods

R_λ=160, 210



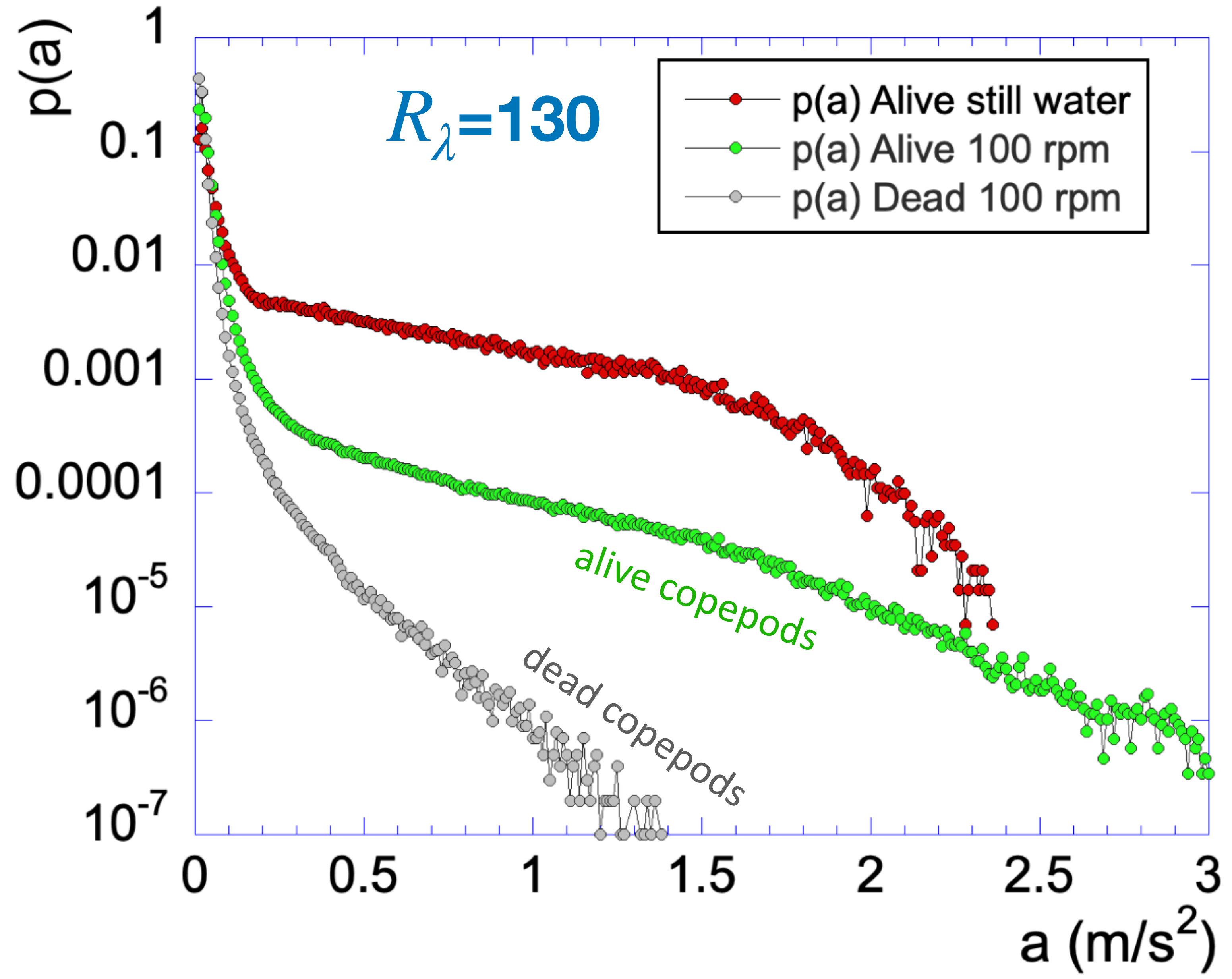


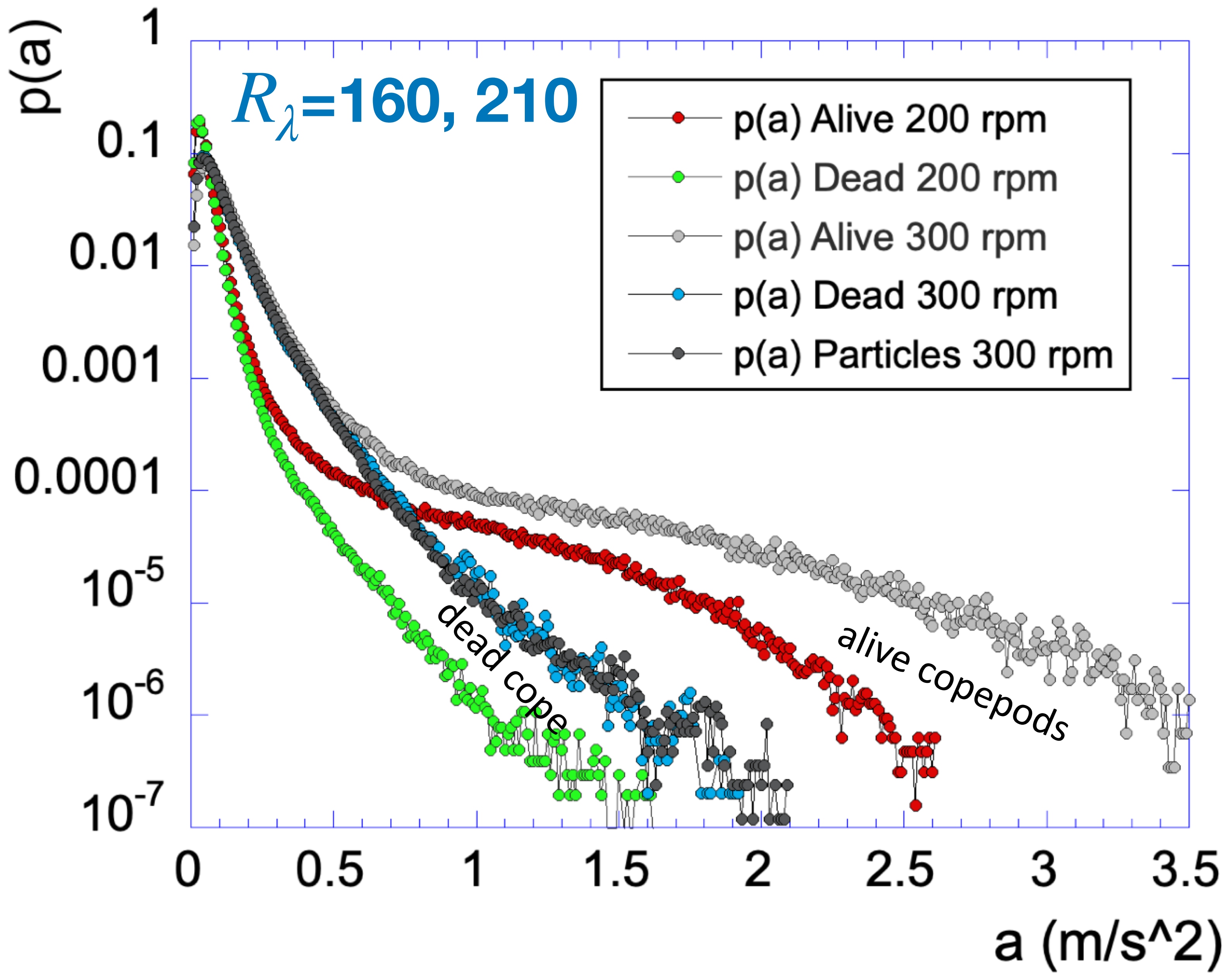
Results: acceleration



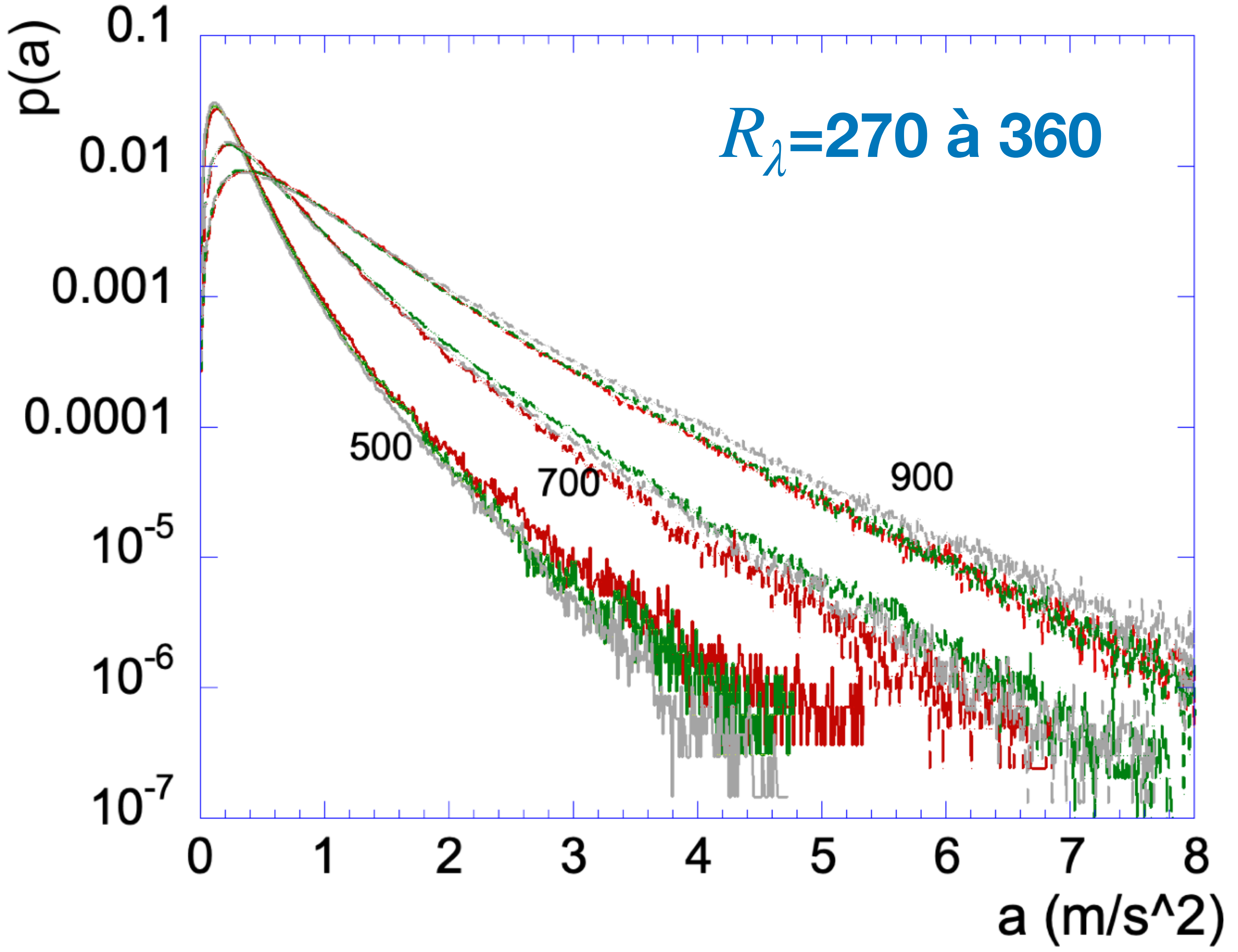
Mean acceleration: no difference

PDF: threshold at R_λ=270, larger than for velocity





No more swimming!



Conclusions:

- This shows that there is an optimal window of turbulence for copepod swimming behavior
- The threshold is not the same for velocity and acceleration
- Quantitative confirmation of the dome effect

Perspectives:

- 3D trajectories (2 simultaneous high speed cameras)
- Lagrangian intermittency (trajectories, velocity, acceleration)

Eur. Phys. J. Plus (2022) 137:250
https://doi.org/10.1140/epjp/s13360-022-02455-7

THE EUROPEAN PHYSICAL JOURNAL PLUS

Regular Article

Check for updates

Copepod swimming activity and turbulence intensity: study in the Agiturb turbulence generator system

Clotilde Le Quiniou[1], François G. Schmitt[1,a], Enrico Calzavarini[2,b], Sami Souissi[1,c], Yongxiang Huang[3,4,d]

Acknowledgements for advices and discussions

- Mickael Bourgoin (ENS Lyon)
- Nicolas Mordant (LEGI Grenoble)

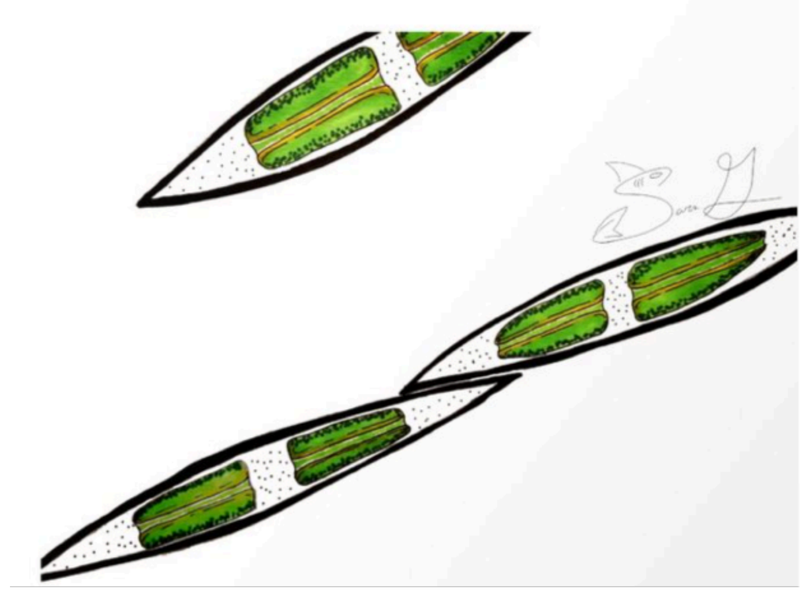
Project
TURBUDIATOX
supported by:

lefe

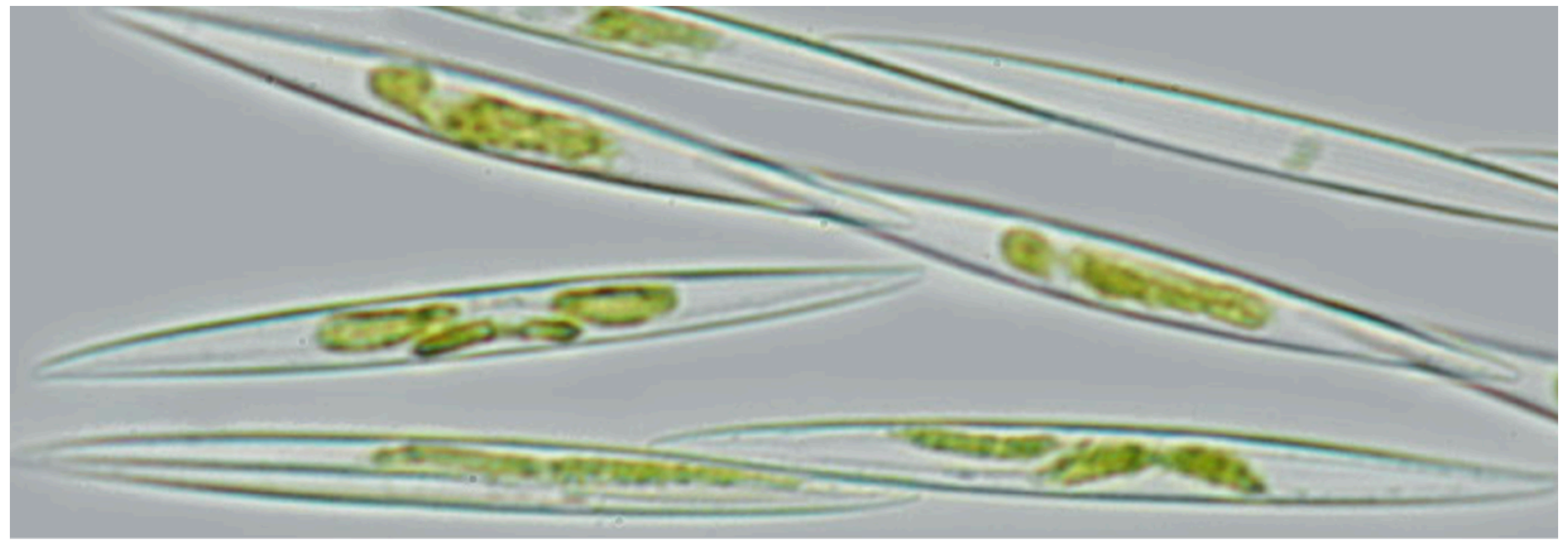
Phycotox
Groupement de Recherche

SFR Campus de la mer
Structure Fédérative de Recherche dédiée à la mer et au littoral dans la région Hauts-de-France

Project Turbu-Diatox
Effects of turbulence on the proliferation and toxicity of diatoms



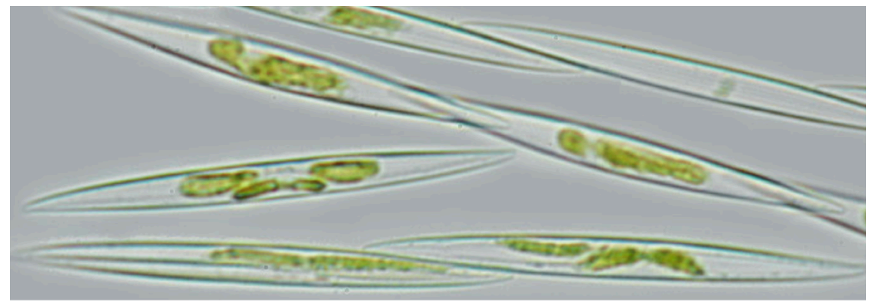
PI: Urania Christaki; François Schmitt



Pseudo-nitzchia: diatoms that can produce toxins such as domoïc acid in some conditions and can produce Harmful algal bloom (HAB).

Main points:

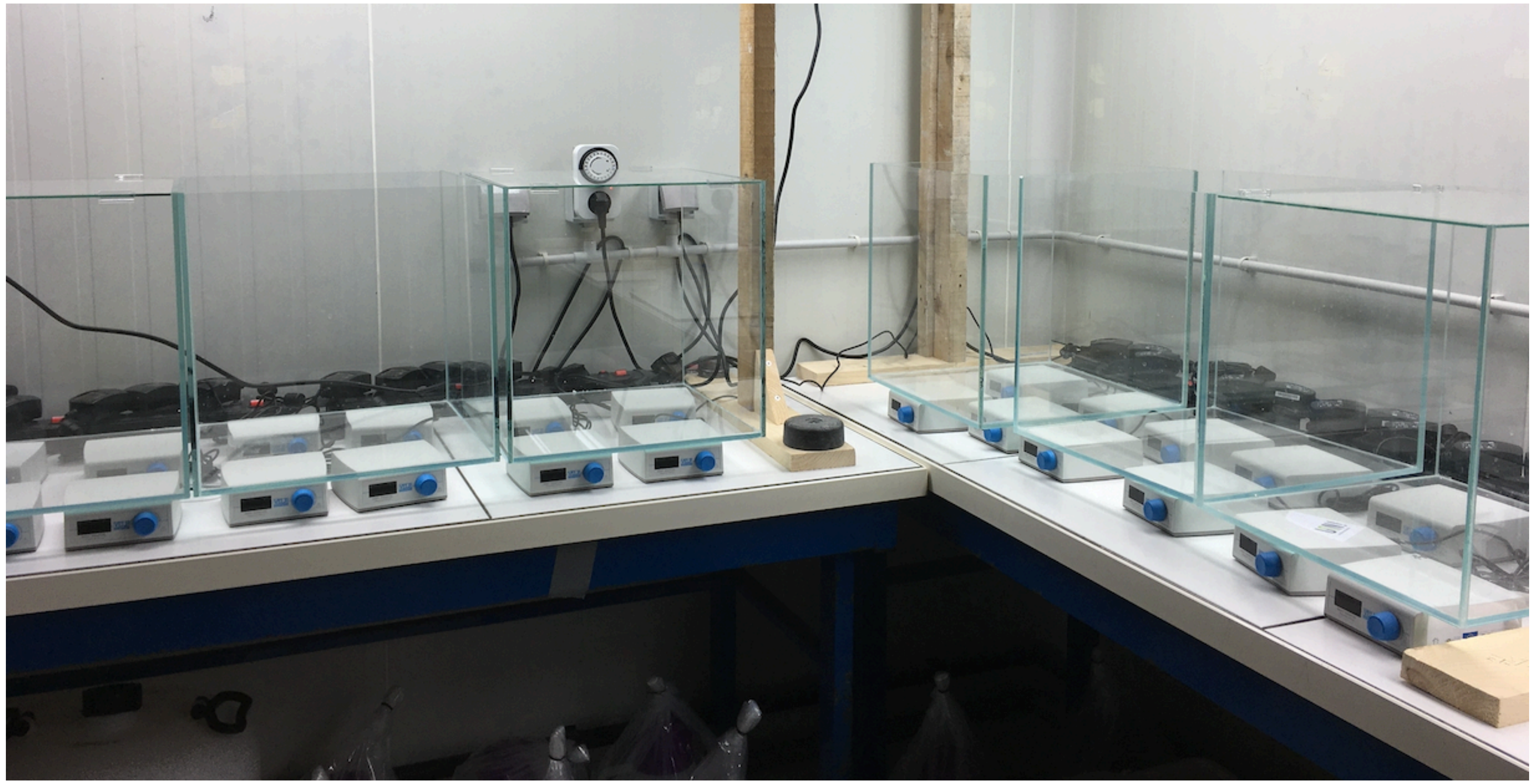
- *Pseudo-nitzschia* has been found regularly in the Eastern English Channel and the south of the North sea (Grattepanche 2011; Breton et al 2017; Delegrange et al 2018) and high abundance have been found in Boulogne-sur-mer (SOMLIT station) in 2018 (Skouroliakou 2018).
- It seems that the morphology and gene expressions in diatoms may depend on turbulence: previous works (Clarson et al 2009; Amato et al 2017).



diatoms *Pseudo-nitzschia*

Method

work of Emilie Houliez (post-doc)



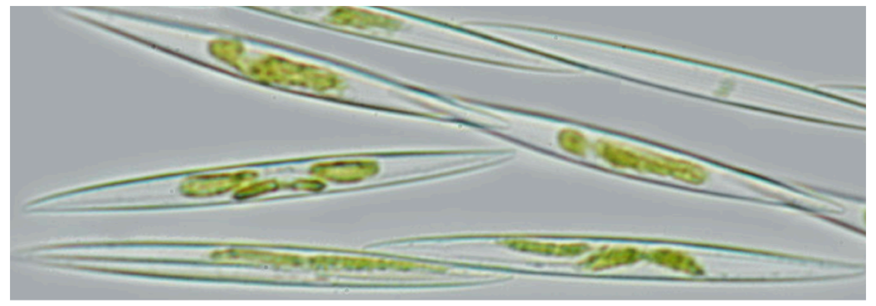
Experimental conditions for the cultures

- 15 °C controlled temperature
- 32 PSU
- 100 µmol photons $m^{-2}s^{-1}$, 12h dark—12h light
- media: K/2

Use of 9 tanks: 6 AGITURB and 3 control

3 replicates each turbulence level

- 3 tanks without turbulence (control)
- 3 AGITURB tanks level 1 of turbulence
- 3 AGITURB tanks level 2 of turbulence



diatoms *Pseudo-nitzschia*

work of Emilie Houliez (post-doc)

Acquisition de 6 systèmes AGITURB

Experiment 1

Control (no turbulence)

Calm

Agitated

Rotation (RPM)	R_λ	Dissipation	Turbulence	Zone
100	130	$3\ 10^{-6}$	Weak	Epicontinental
200	160	10^{-5}	Calm	Coastal zone
400	240	10^{-4}	Agitated	Surf zone
900	360	10^{-3}	Strong	Storm

Experiment 2

Control (no turbulence)

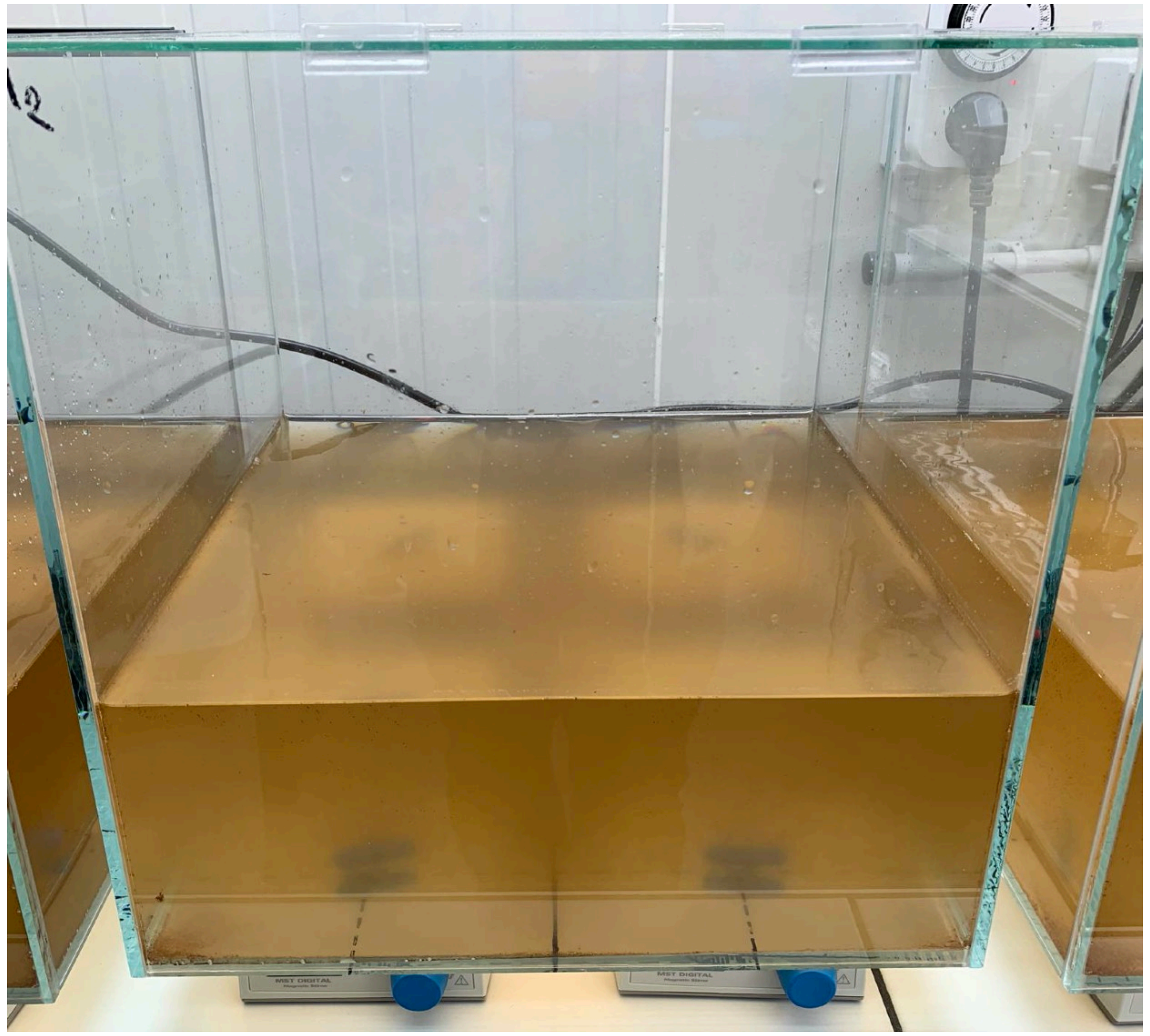
Weak

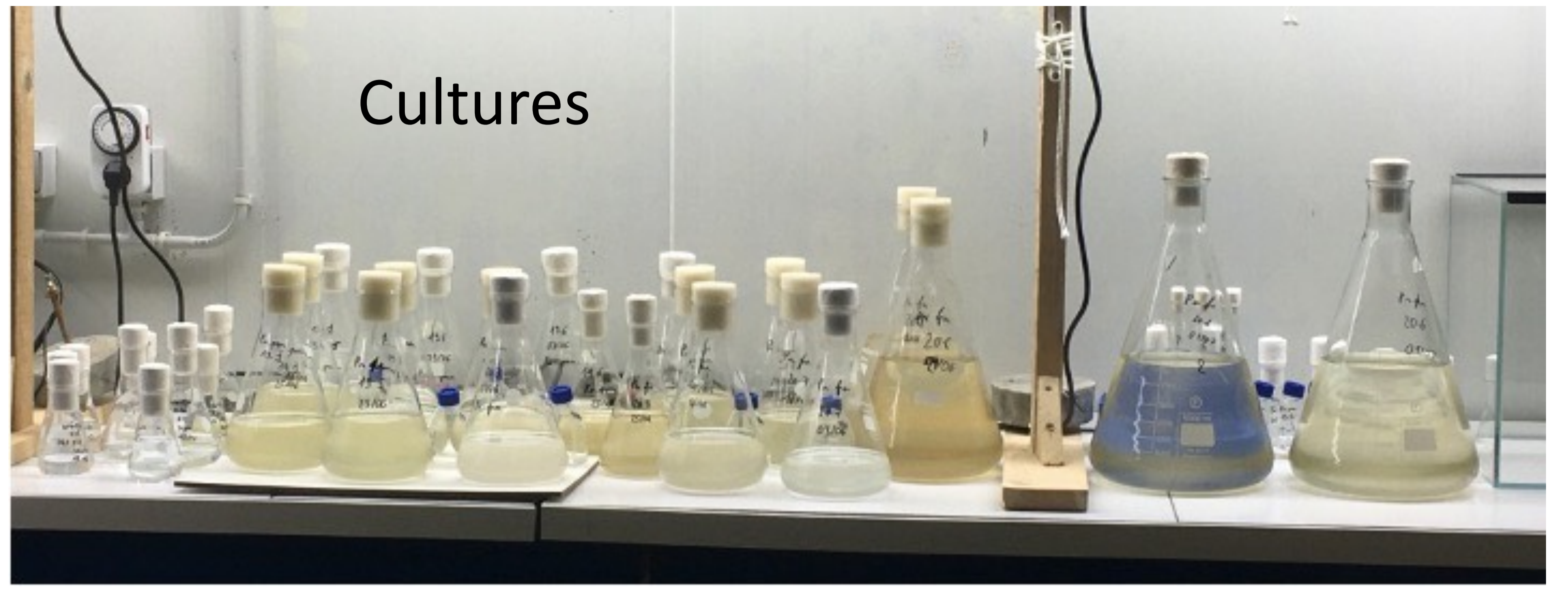
Strong

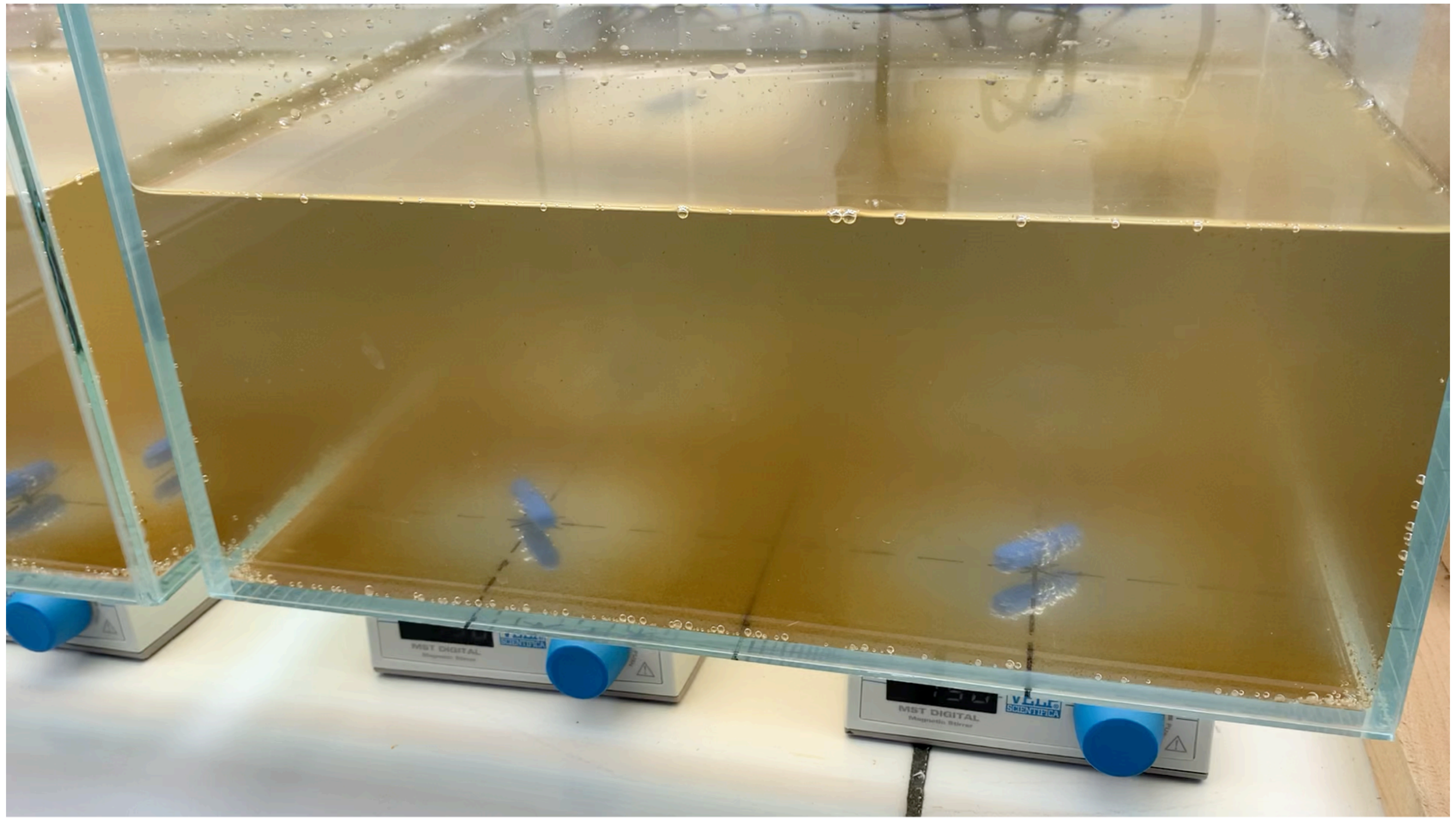
Sampling at T=0, T=24h, T=48h, T=72h.

Measurements of:

- **Growth** (cell counts by microscopy)
- **Chains length** (by microscopy)
- **Pigments** (spectrophotometry)
- **Toxins** (ELISA) particulate and dissolved
- **Meta T**: for chosen samples
- **Nutrients** (NO2-, NO3-, Si, PO43-)
- **pH**
- **Bacteria / viruses** (flow cytometry)




Cultures



First results: growth rate

Log-scale plots

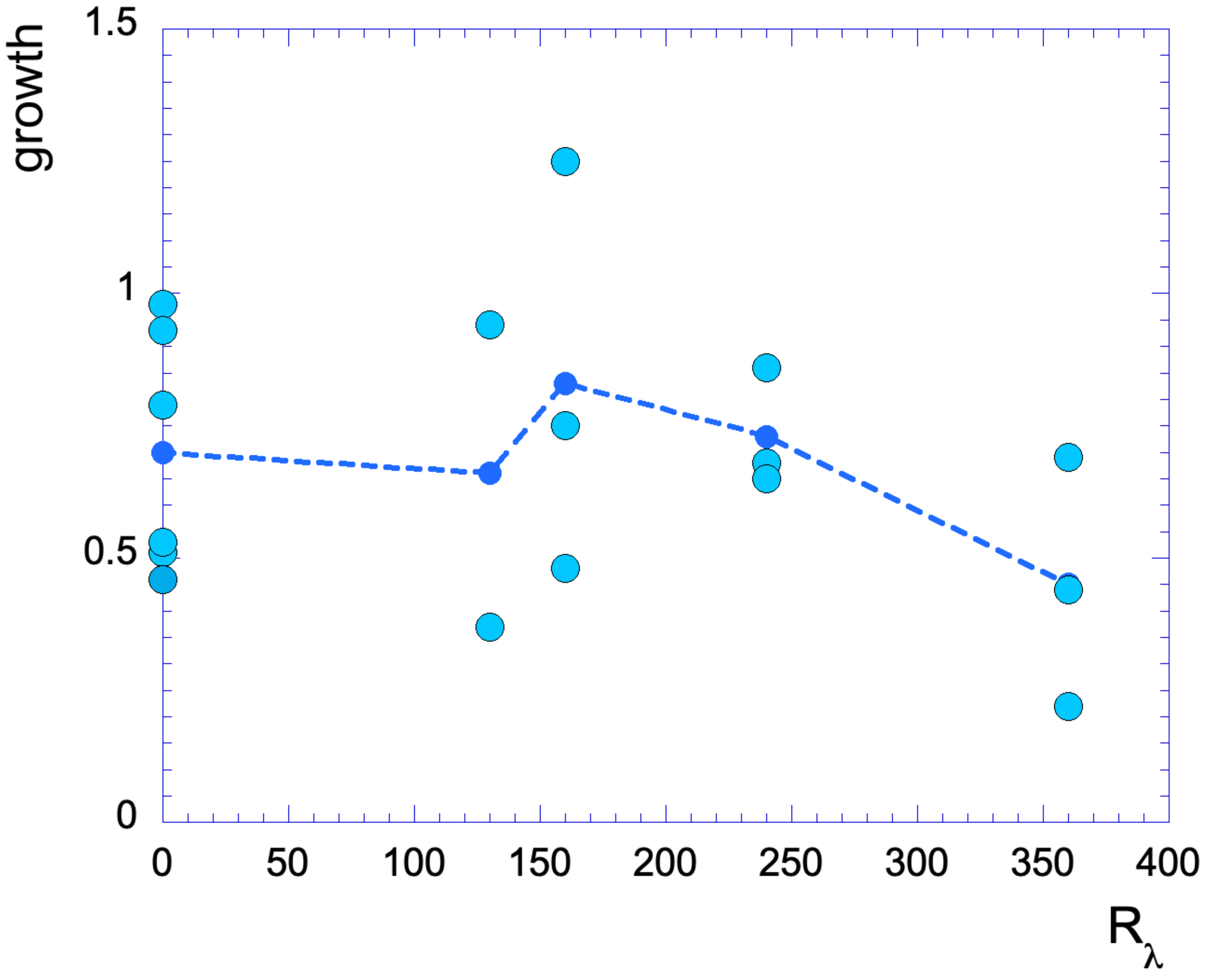
In case of exponential growth, we have: $N(t) = N_0 \exp(\mu t)$, where N_0 is the initial number of celles, and μ is the growth rate.

This gives, in log-scale: $\log N(t) = \log N_0 + \mu t$, hence a straight line, with slope μ. The range of times for which the straight line is found corresponds to the exponential growth.

Graphically estimate the growth rate as:

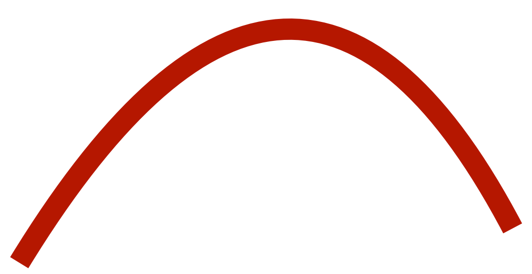
$$\mu = \frac{\log \frac{N(T_{\max})}{N(T_{\min})}}{T_{\max} - T_{\min}} = \frac{\log N(T_{\max}) - \log N(T_{\min})}{T_{\max} - T_{\min}}$$

Curve of the growth rate versus the Reynolds number
First results

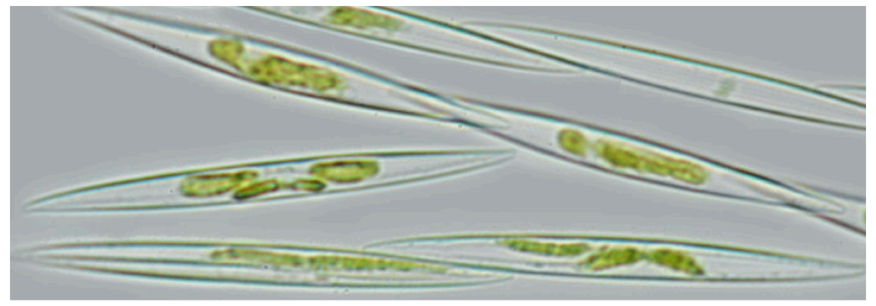


Preliminary conclusions

- There is a slight **dome shape**



- No turbulence and low turbulence are similar
- There is an **optimum** and then the growth rate goes down with the turbulence intensity
- For a very large turbulence level (« storm » here) the growth rate is lower than without turbulence

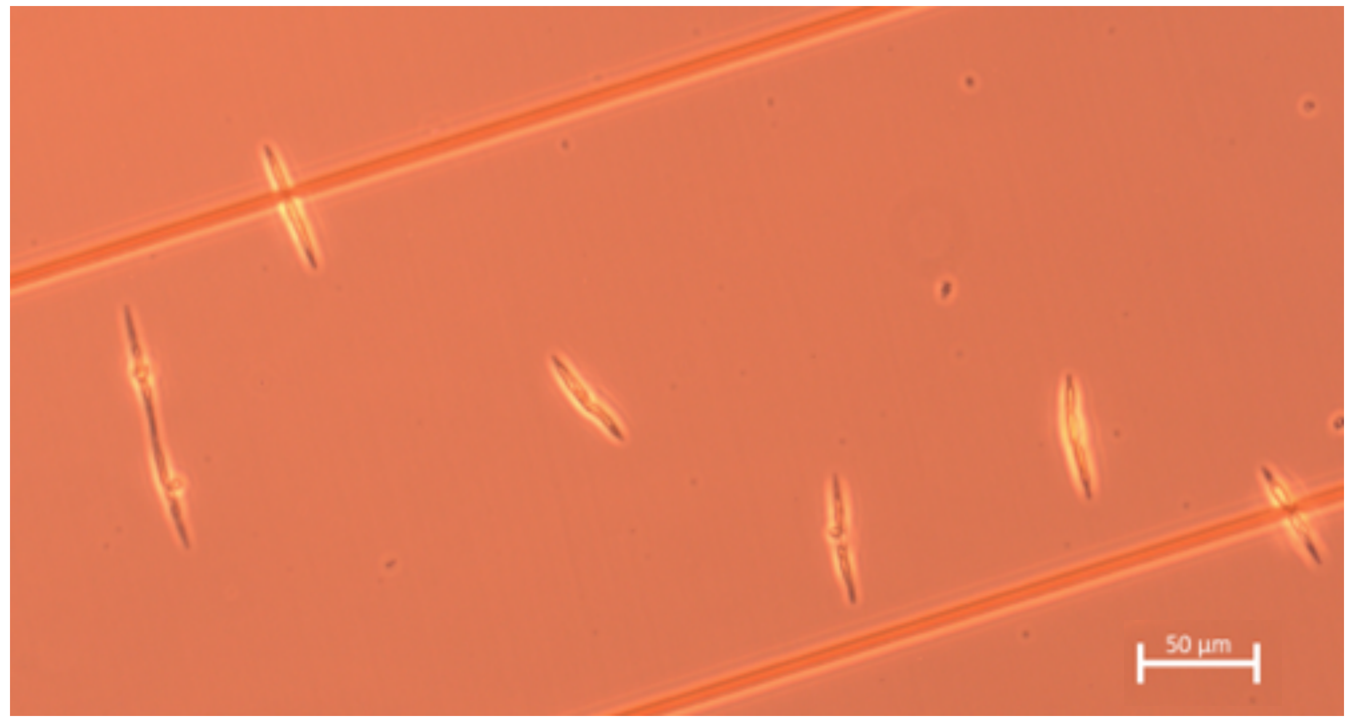


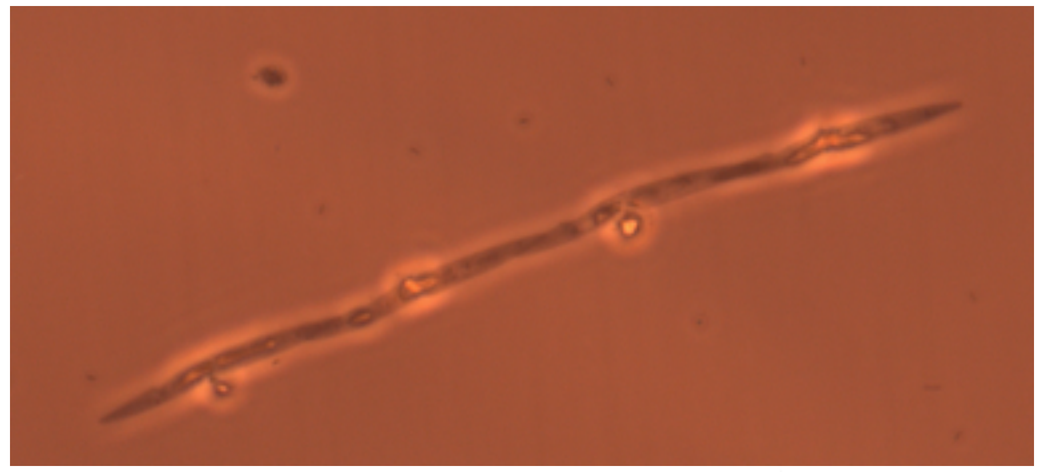
diatom *Pseudo-nitzschia*

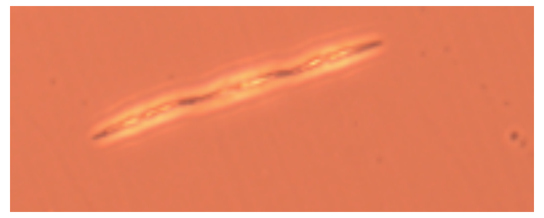
First results: chains

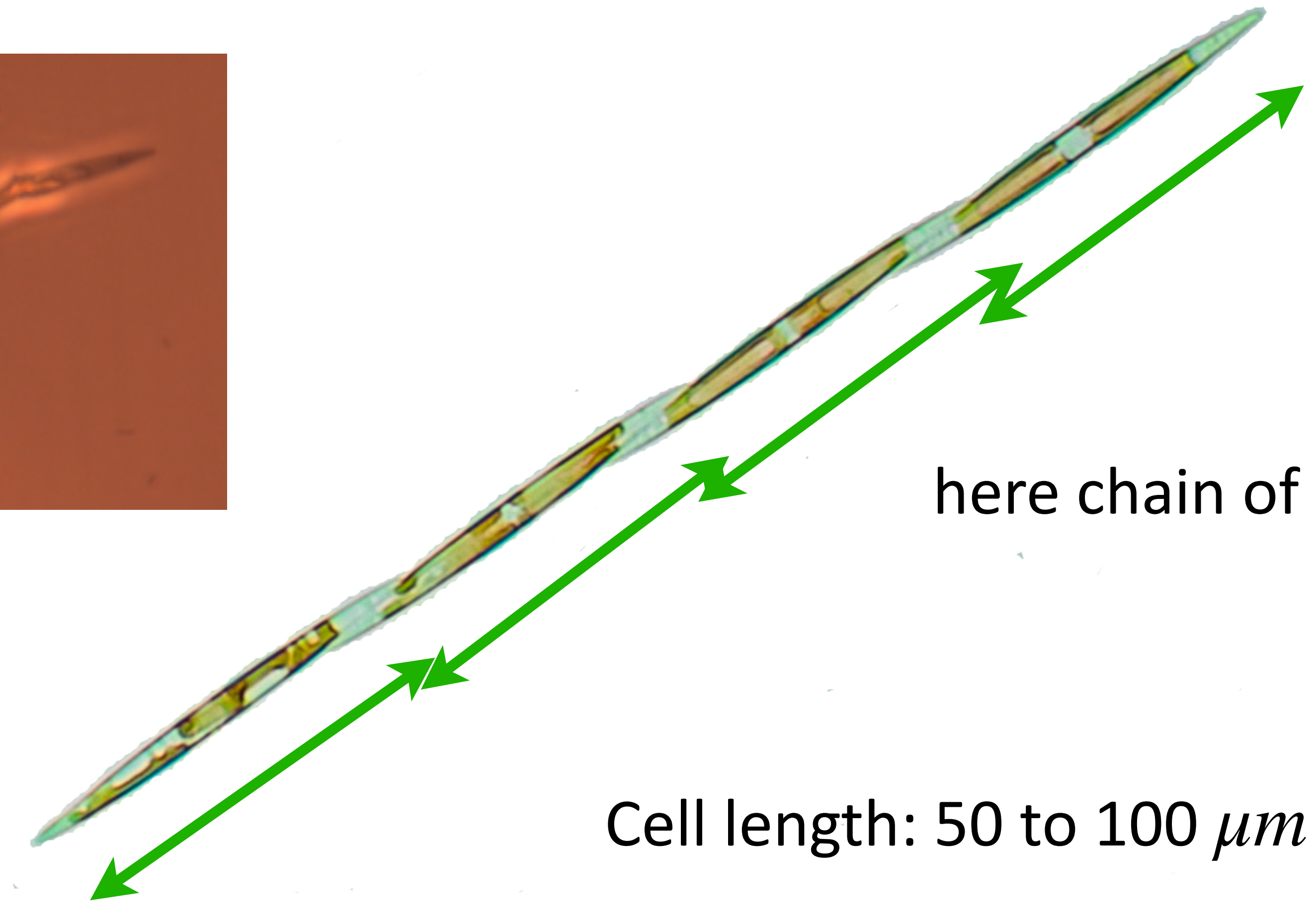
Work of Emilie Houliez (post-doc) and Vasileios Bampouris (Erasmus)

isolated cells, or chains









Methodology

- Counting of the chain length for samples taken in each tank
- Three classes considered: isolated cells (1 cell); short chains (2 or 3 cells); long chains (4 cells or more)
- Estimation of the percentage, averaged over different replicates
- Comparison of the time dynamics of the percentage (0, 1, 2 or 3 days)
- Comparison of the percentages at a given time for each Reynolds number R_λ

First results: chain dynamics

Isolated cells

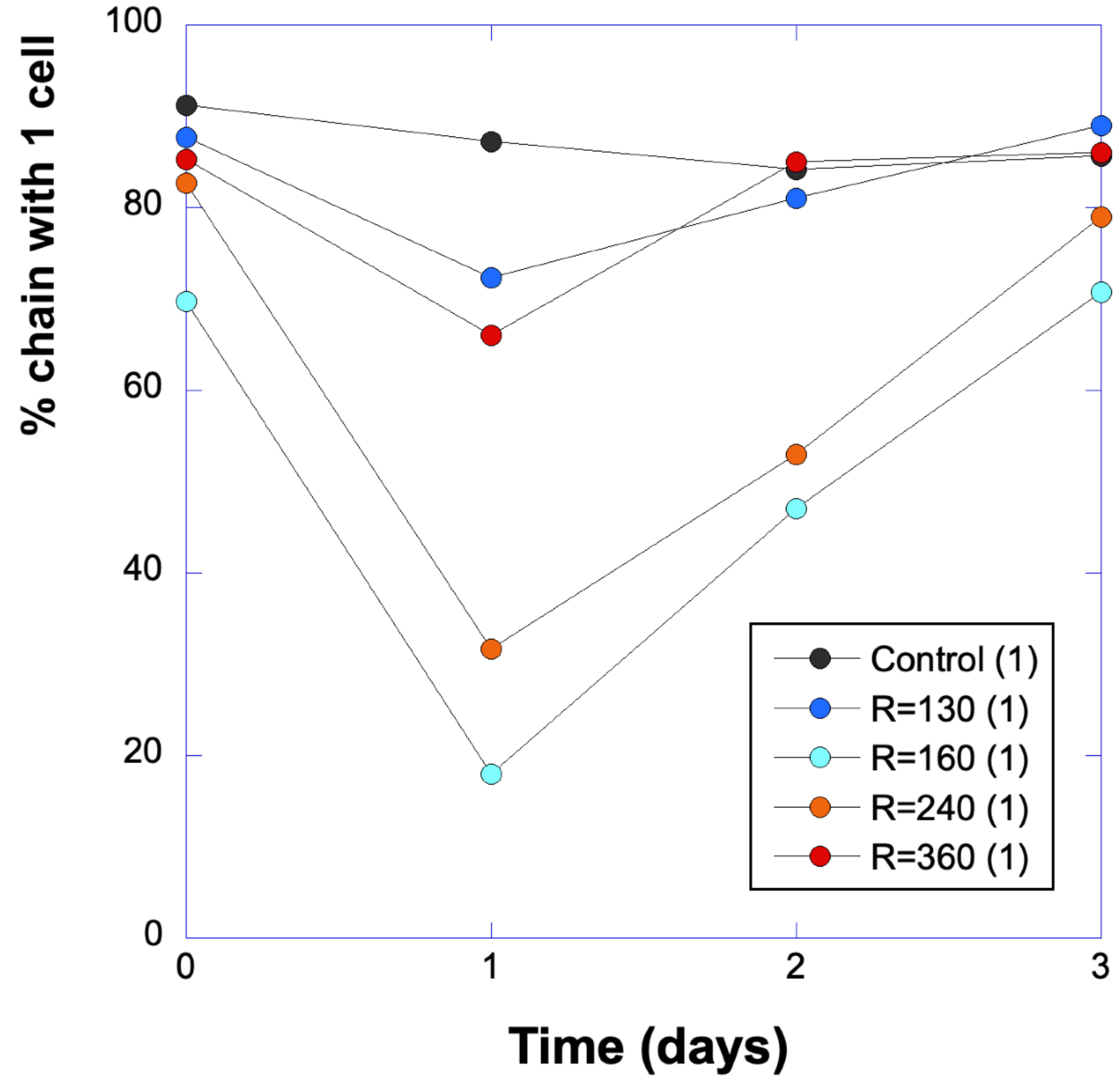
- For each turbulence level, a minimum at 24h, and then increase of the percentage
- The minimal value at 24h depends on the turbulence level, with a minimum for $R_\lambda = 160$

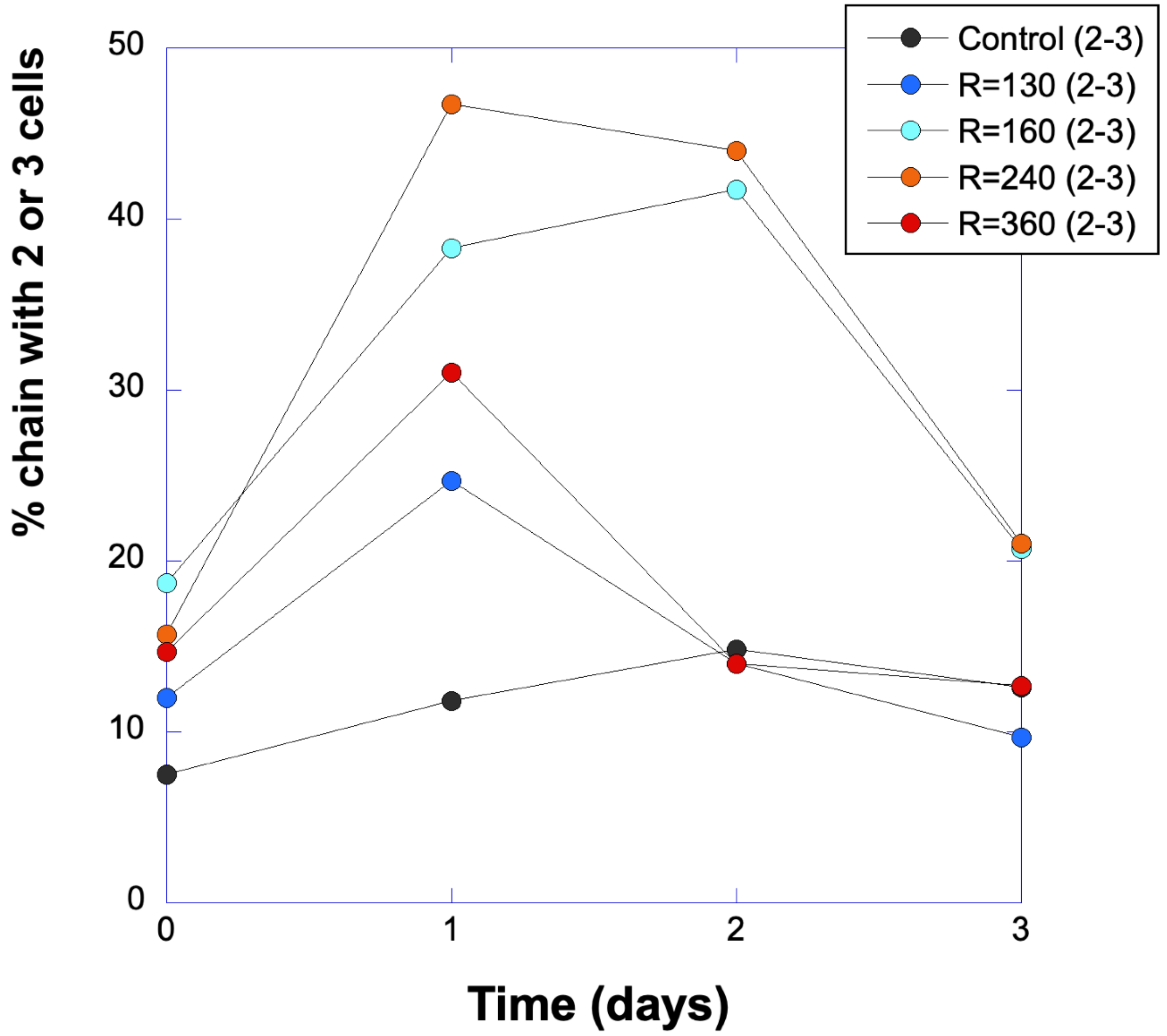
Short chains

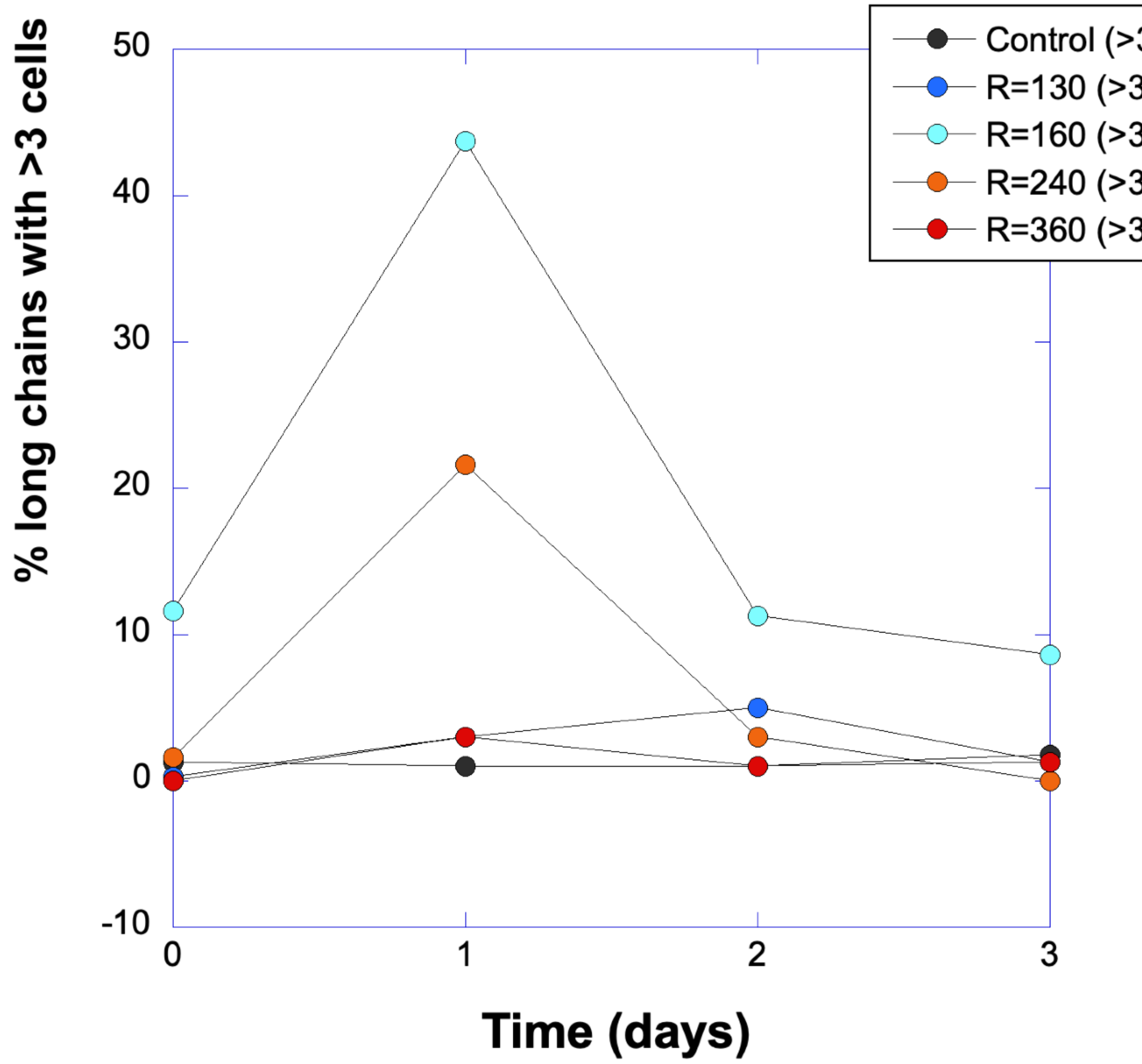
- For each turbulence level, a maximum at 24h or 48h, and then decrease of the percentage
- The maximum value is the larger for $R_\lambda = 240$

Long chains

- The rate is large only for 3 turbulence levels: $R_\lambda = 160$ and 240
- A pike is found at 24h, and then decrease







First results: Reynolds number dependence

Isolated cells

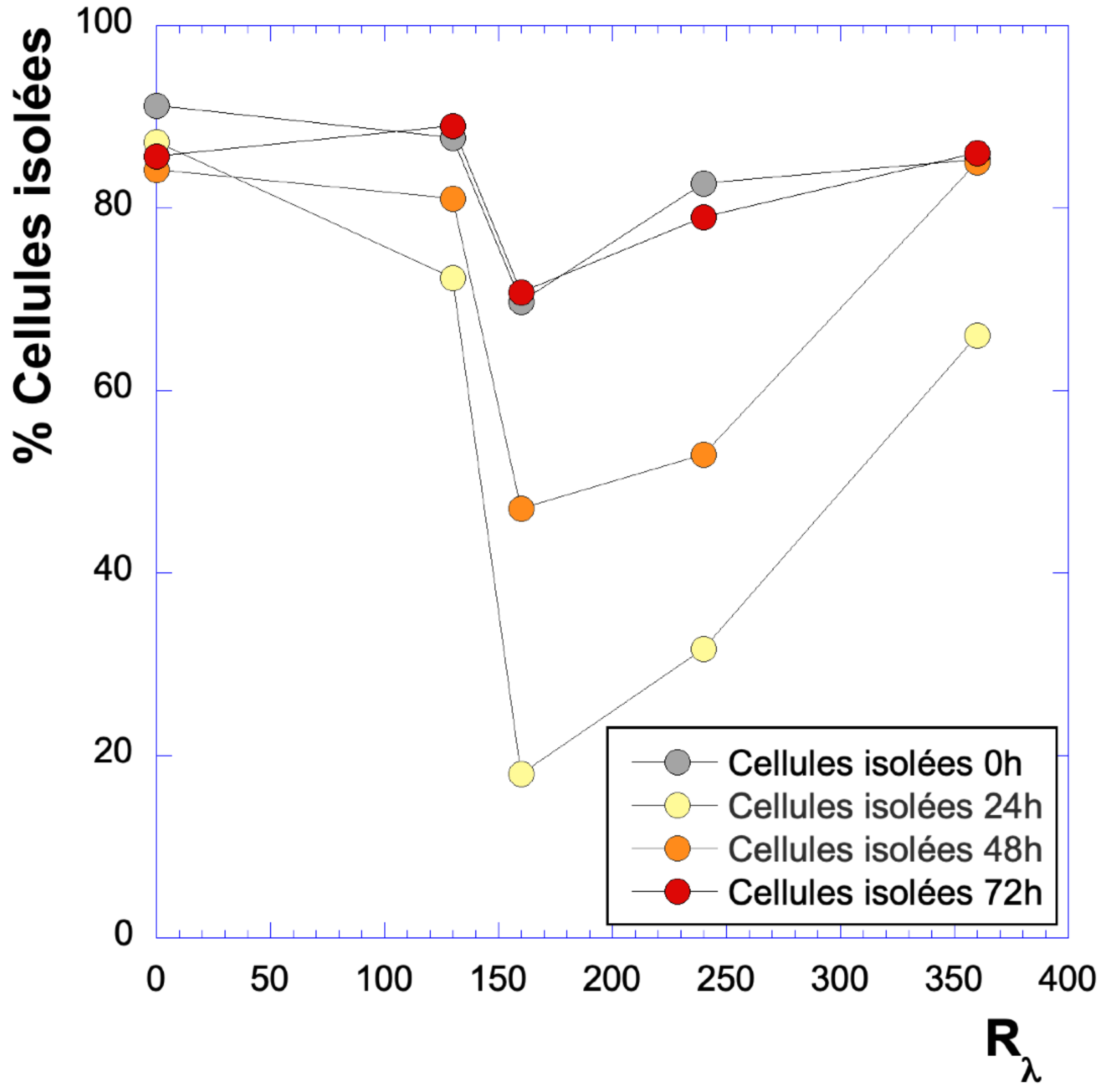
- There is a minimum at 24 and 48h
- the minimum is the smaller at $R_\lambda = 160$

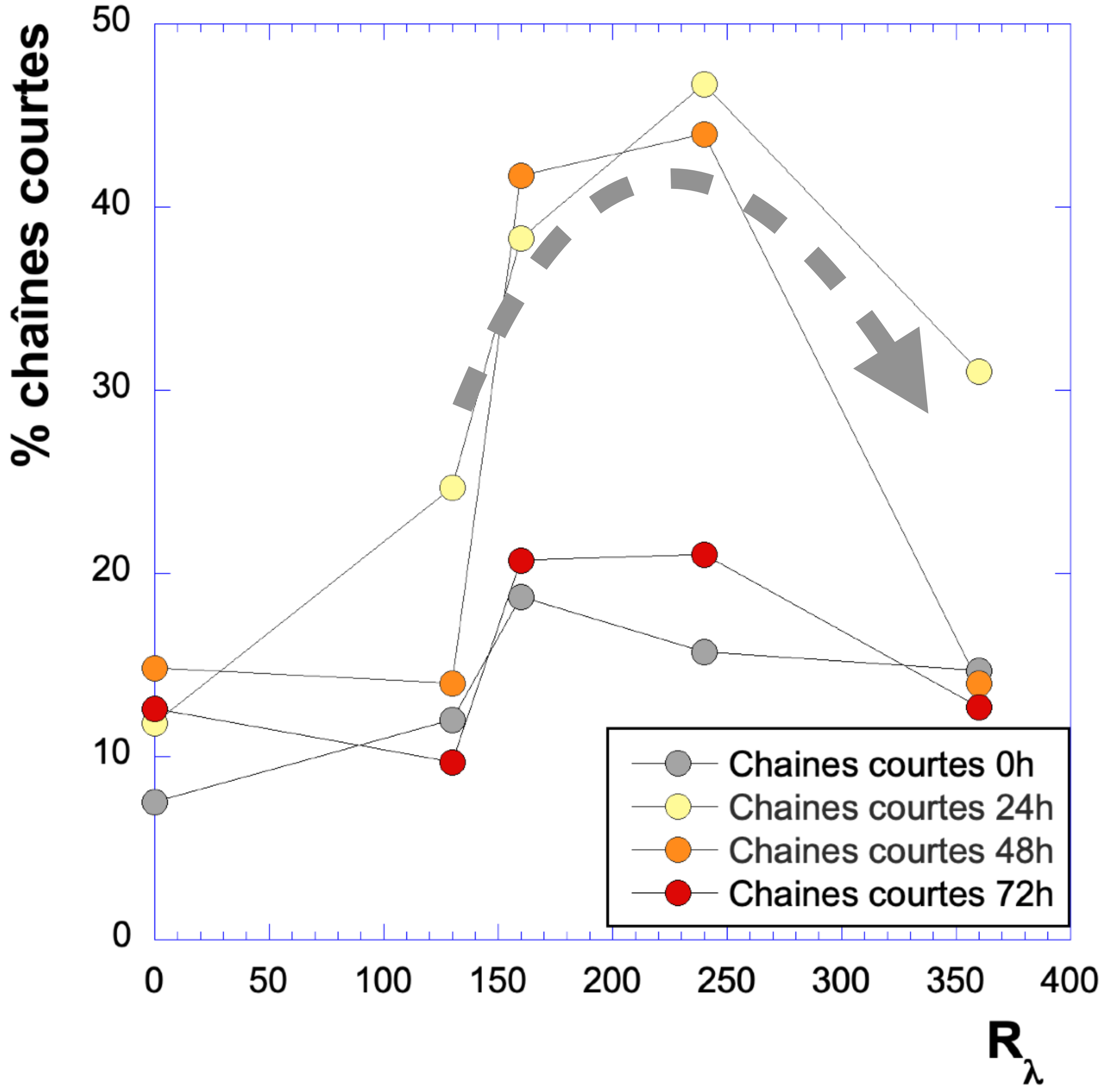
Short chains

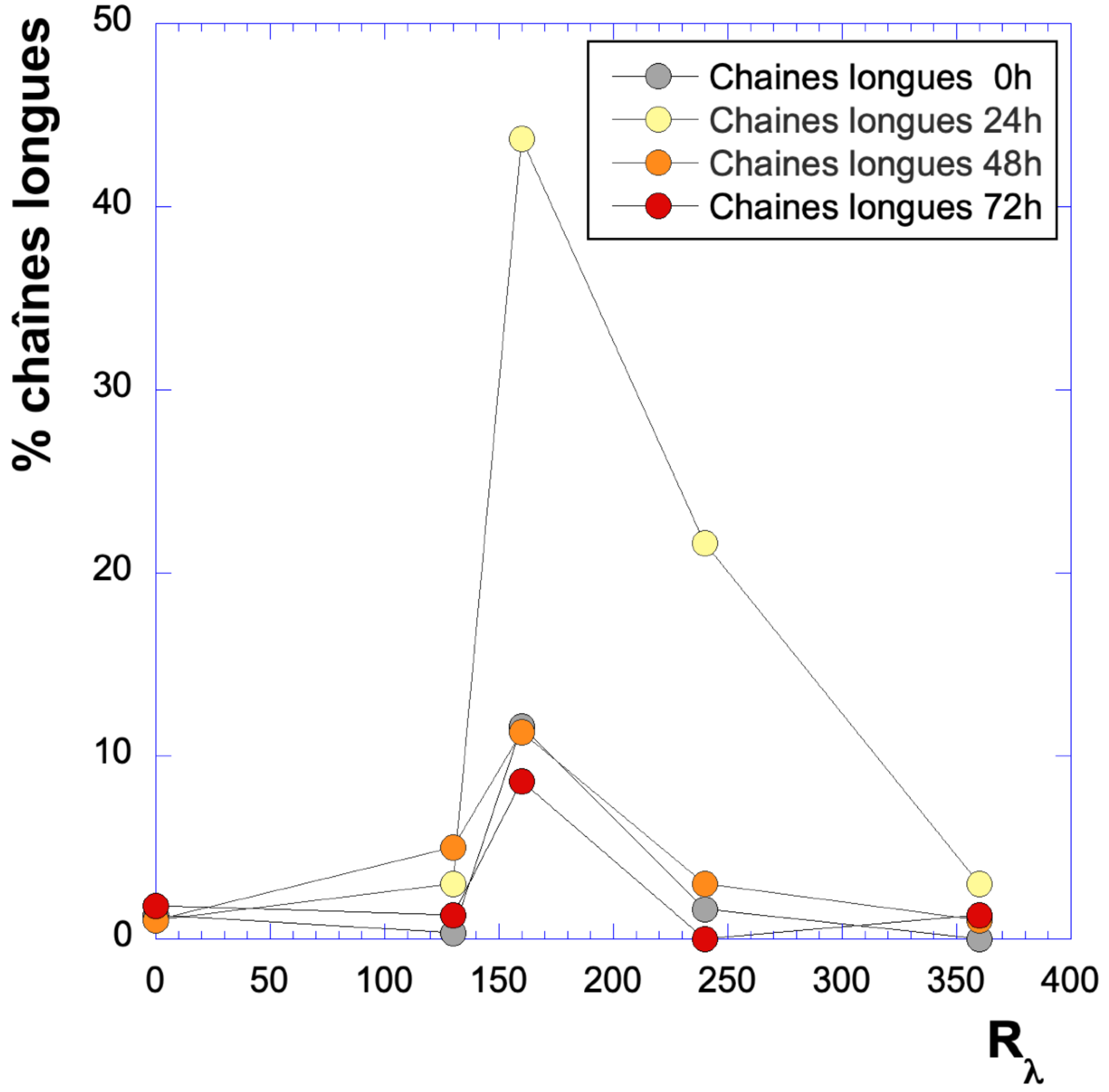
- At 24h and 48h, the levels are similar
- There is a maximum between 24 and 48h, for $R_\lambda = 240$
- There is a clear **dome effect** for short chains, with an optimal turbulence level

Long chains

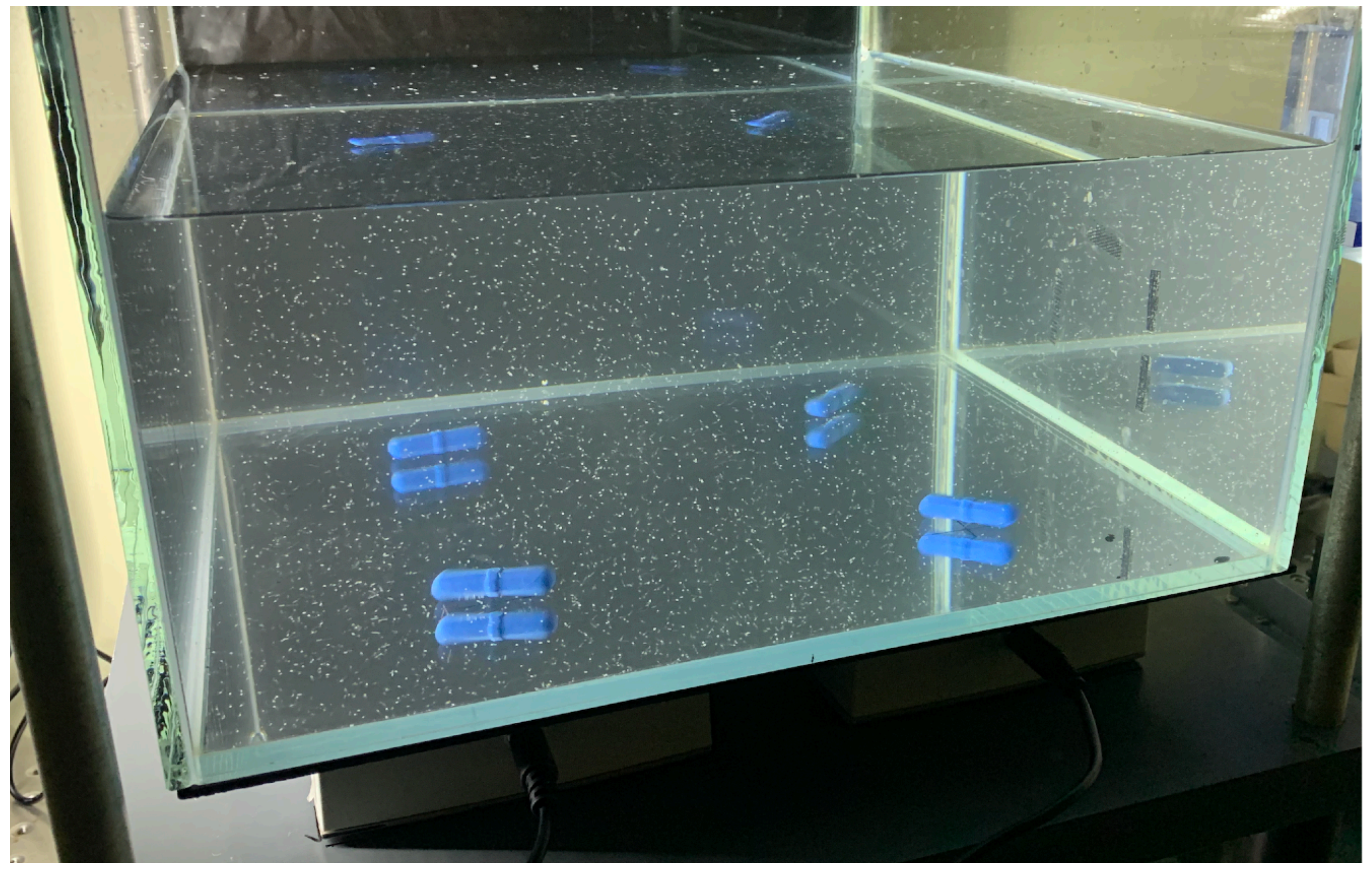
- The proportion is important only at 24h
- There is a turbulence window at $R_\lambda = 160$
- The long chains last for 24h and only for a well defined turbulence level

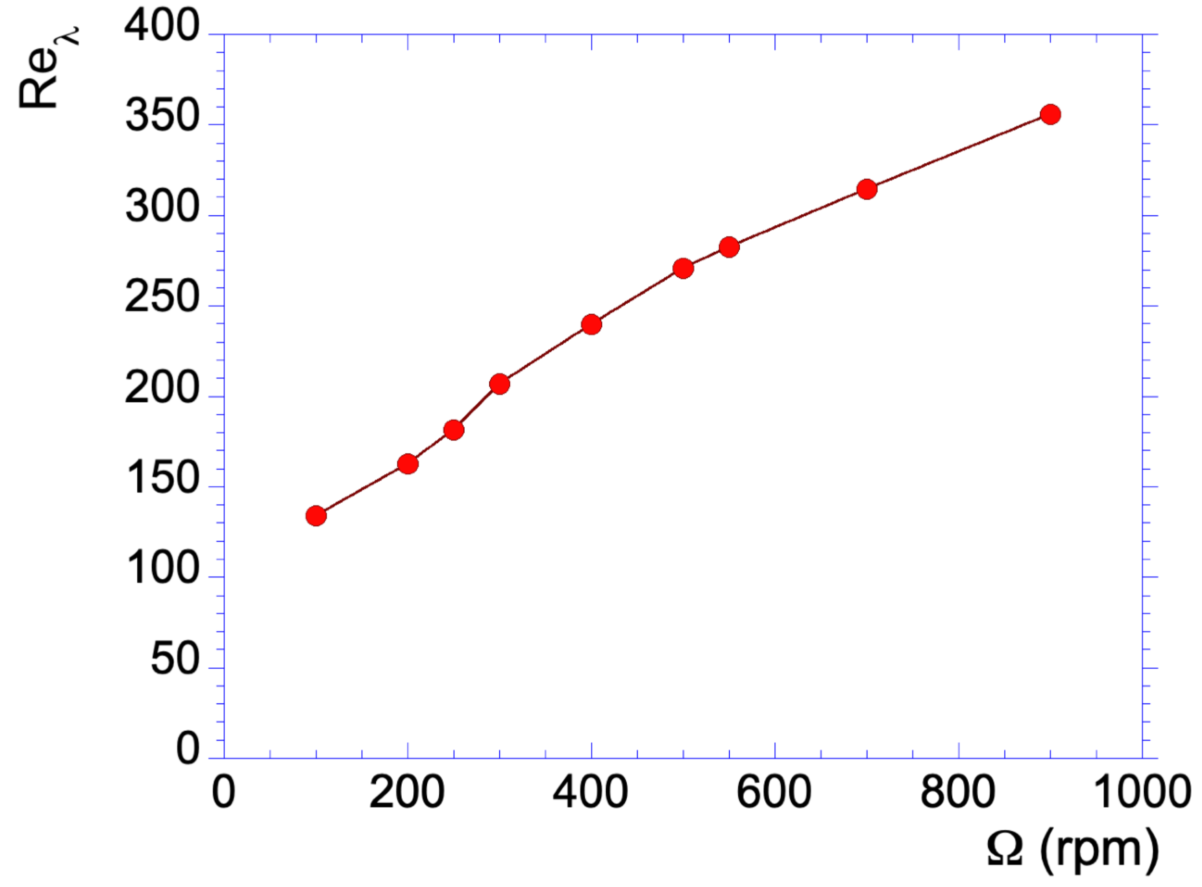




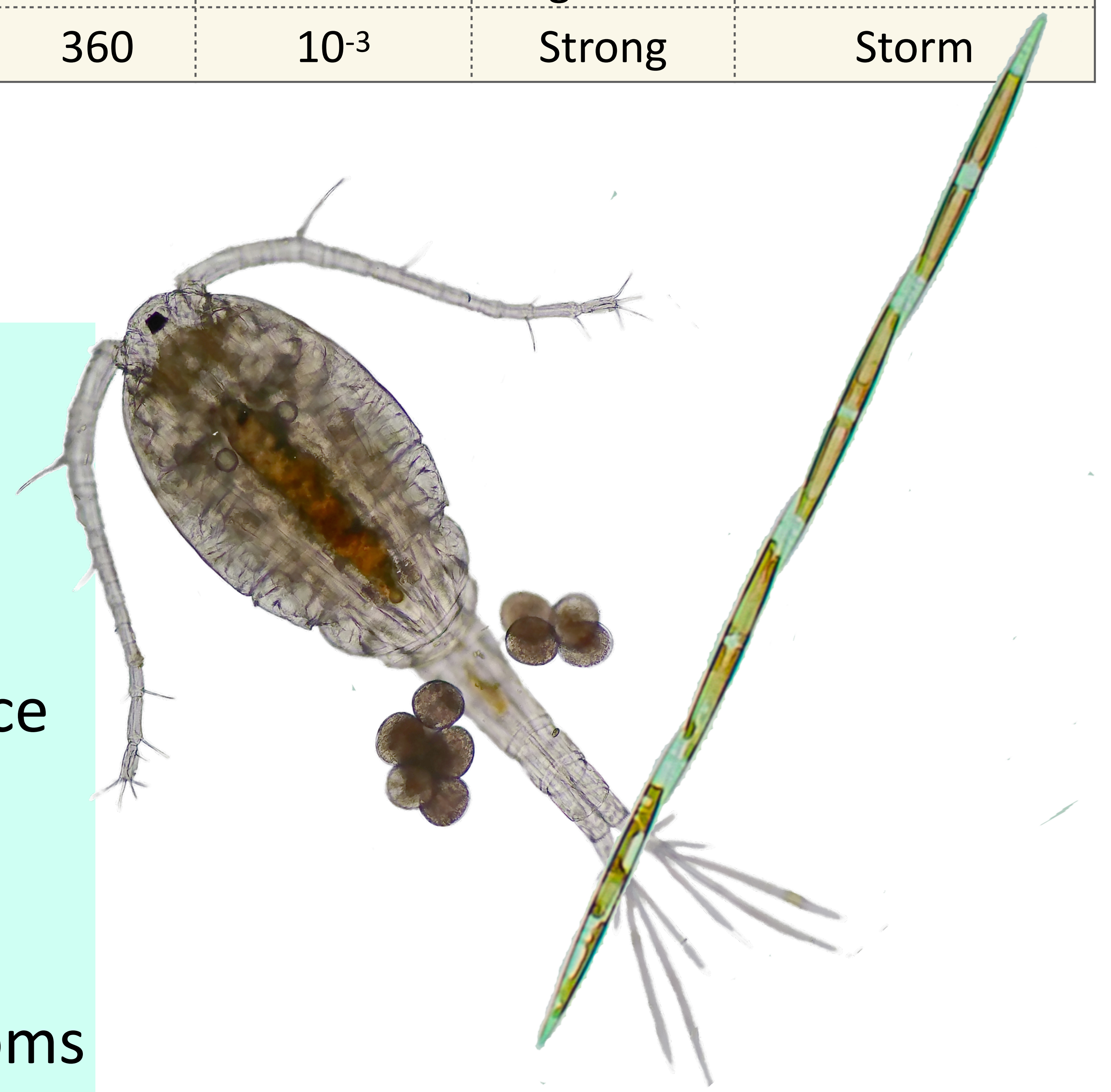


Conclusions





Rotation (RPM)	R_λ	Dissipation	Turbulence	Zone
100	130	3 10^{-6}	Weak	Epicontinental
200	160	10^{-5}	Calm	Coastal zone
400	240	10^{-4}	Agitated	Surf zone
900	360	10^{-3}	Strong	Storm



- The new AGITURB system is cheap (~1000 €), easy to build, and able to generate controlled turbulence level in the laboratory
- The turbulence level is characterized by the dissipation rate and the microscale Reynolds number R_λ ranging from 130 to 360, corresponding to ranges of turbulence representative of the field
- For copepods and diatoms, optimal levels are found, with some **dome effect** for copepod **swimming behaviour**, and for **growth rates** and **chain formations** of diatoms
- Some optimal values found for R_λ =160 or 240, depending on the considered application.

Acknowledgement of financial support

Project MARCO 2015-2021

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE
PRÉFET
DE LA RÉGION
HAUTS-DE-FRANCE

French state

Region Hauts-de-France

European Union

Ifremer

UNION EUROPEENNE

l'Europe s'engage en Hauts-de-France

Région Hauts-de-France

Ifremer

MARCO

Project TURBUDIATOX 2021-2022

lefe

cnrs

ulco
Université
Littoral Côte d'Opale

Phycotox
Groupement de Recherche

SFR
Campus de la mer
Structure Fédérative de Recherche
dédiée à la mer et au littoral
dans la région Hauts-de-France

Cambridge University Press, 2016

thank you for your attention

Ellipses, 2020