Long-range effects of walls in schooling fish

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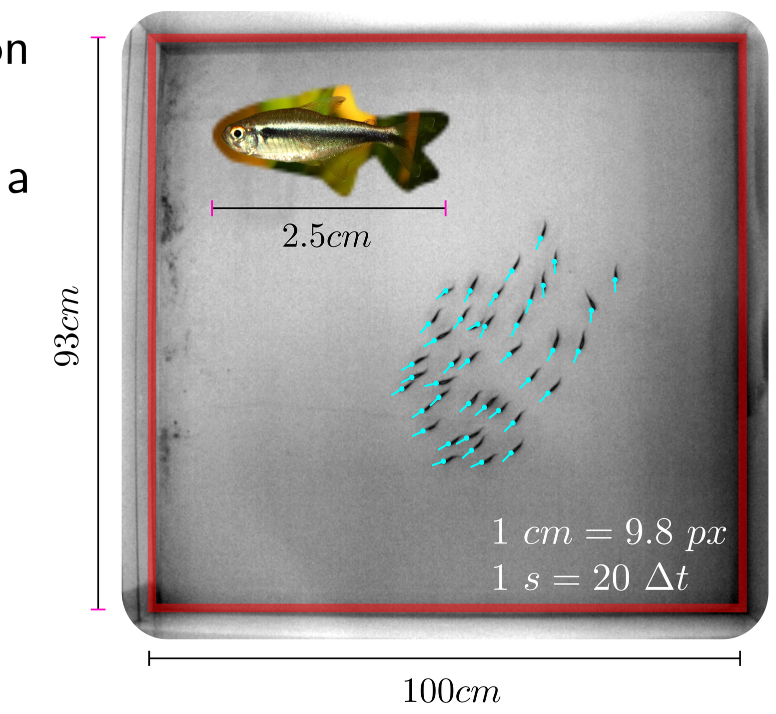
Collective motion occurs when a system of self-propelled units exhibit spontaneous ordered movement. It is ubiquitous in the real world, arising in systems of many different scales. Here, we approach the topic considering **fish schools**.

One major challenge is to capture and quantify the interactions that drive the movement, both at the individual and collective level. This includes the cooperation between individuals and the responses to external elements, such as the presence of walls in a tank. Few works have tried to address the **interactions with the walls**, most of them investigating schools of only one or two fish[1-4], finding short-range interactions decaying exponentially.

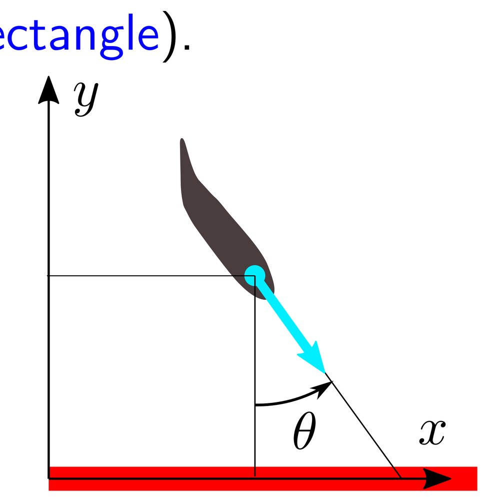
Here we aim to analyse quantitatively the experimental interactions of schooling fish with the tank walls and use this information to build a random walk model reproducing some key features of the system.

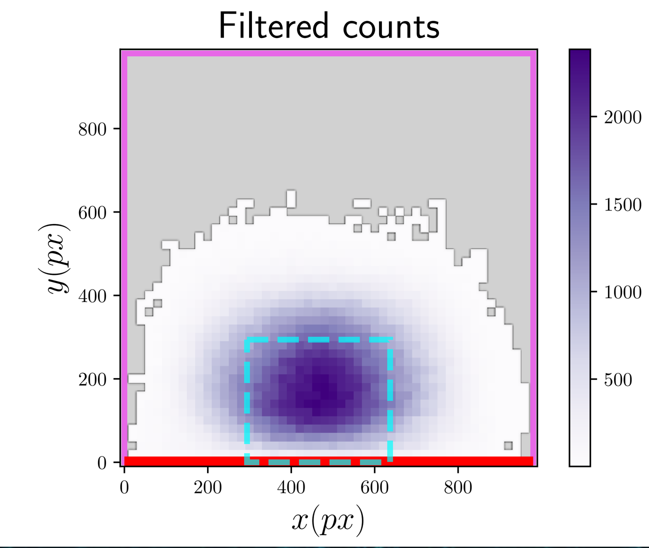
[1]Calovi, Daniel S., et al. "Disentangling and modeling interactions in fish with burst-and-coast swimming reveal distinct alignment and attraction behaviors." PLoS computational biology 14.1 (2018): e1005933.
[2]Zienkiewicz, Adam K., et al. "Data-driven modelling of social forces and collective behaviour in zebrafish." Journal of theoretical biology 443 (2018): 39-51.
[3]Gautrais, Jacques, et al. "Analyzing fish movement as a persistent turning walker." Journal of mathematical biology 58.3 (2009): 429-445.
[4]Gautrais, Jacques, et al. "Deciphering interactions in moving animal groups." (2012): e1002678.

Our school consists on 40 black neon tetra (*Hyphessobrycon herbertaxelrodi*) freely swimming in a shallow tank (5 cm of depth). Three independent segments were recorded of 10 minutes of duration (1200 frames each). The trajectory of individual fishes was digitized using a custom-made tracking software built in Python.



For each of the four walls, we define the coordinates of a fish relative to the wall (x, y) and its orientation θ. In order to reduce the effects of the other walls, we discard all data points for which the center of mass of the school is outside the nearest central region of the wall (blue dashed rectangle).

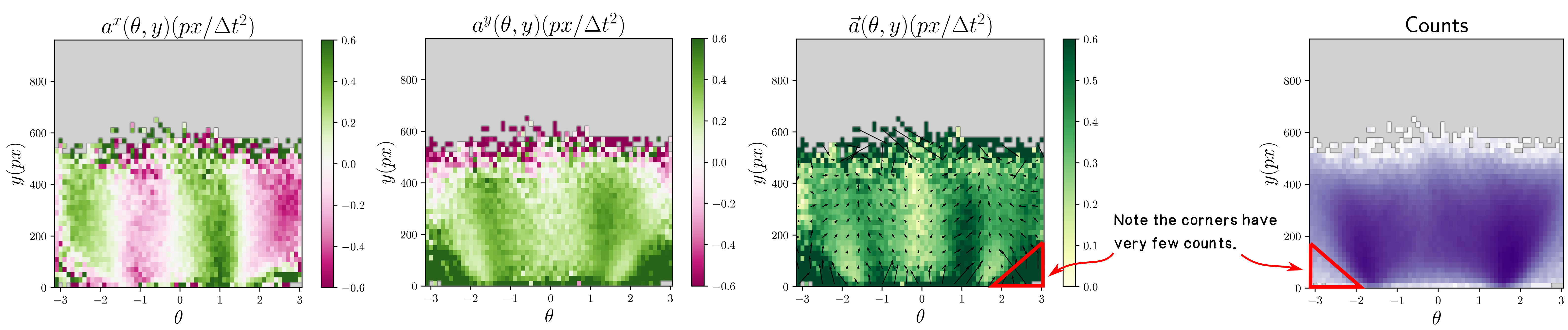




1. Experimental interactions

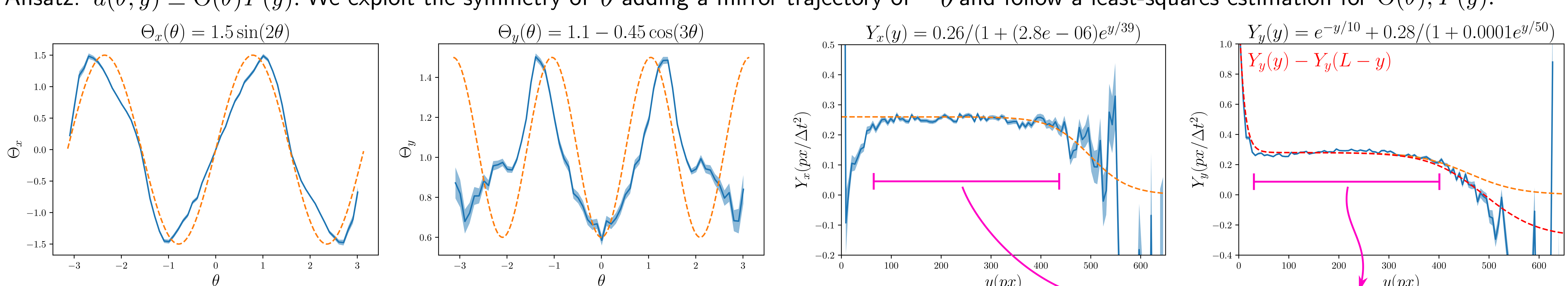
For the force of each wall we assume: $\boxed{\vec{F}(\theta, y)}$

We work with $m \equiv 1$, so $\vec{F} = \vec{a}$.



2. Fitting procedure

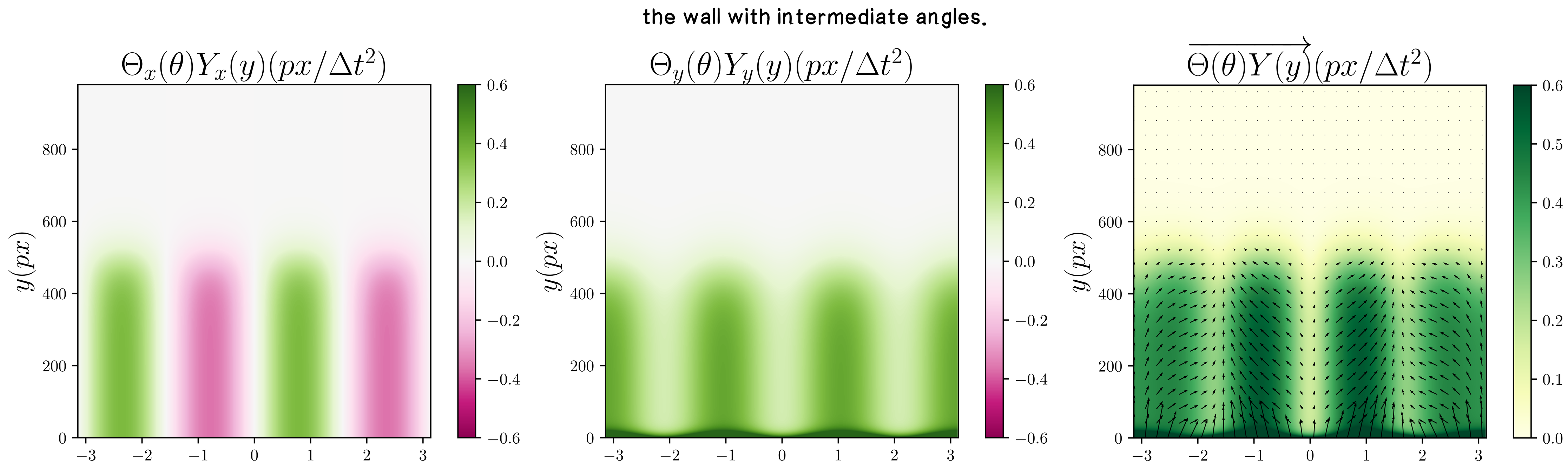
Ansatz: $\vec{a}(\theta, y) \equiv \overrightarrow{\Theta(\theta)Y(y)}$. We exploit the symmetry of θ adding a mirror trajectory of $-\theta$ and follow a least-squares estimation for $\vec{\Theta}(\theta), \vec{Y}(y)$.



Fish tend to become parallel to the wall.

Fish feel a stronger repulsion when approaching the wall with intermediate angles.

The walls have a long-range effect!



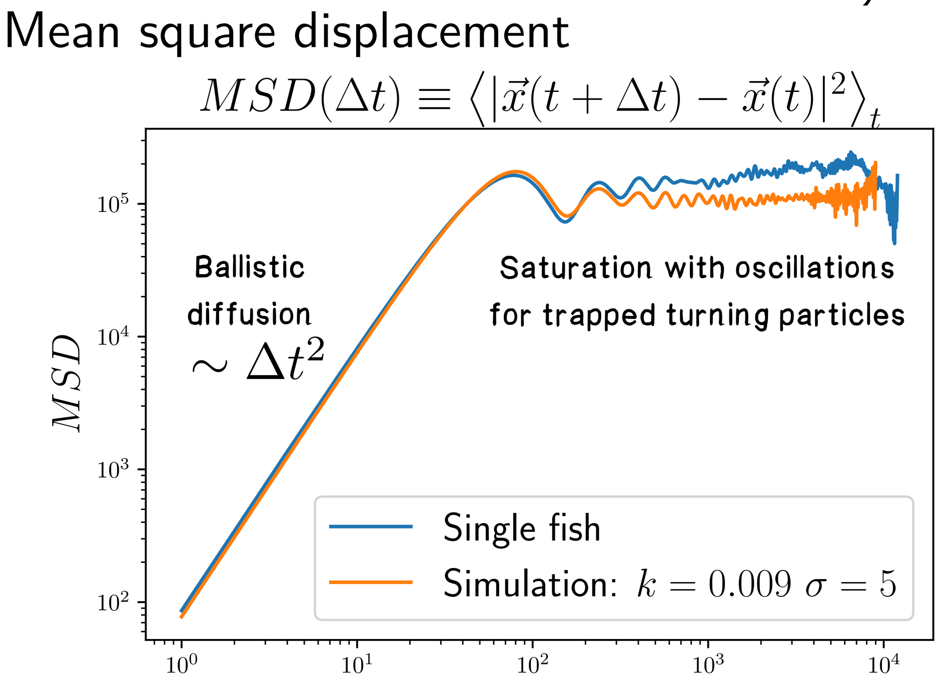
3. Modeling trajectories of fish

$$\frac{d^2\vec{x}}{dt^2} = \sum_w \overrightarrow{\Theta(\theta)Y(y)} - k\frac{d\vec{x}}{dt} + \vec{N}(0, \sigma^2).$$

Total force — Sum of forces for the four walls — Friction — Gaussian noise (masks other interactions)

Mean square displacement

$$MSD(\Delta t) \equiv \langle |\vec{x}(t + \Delta t) - \vec{x}(t)|^2 \rangle_t$$

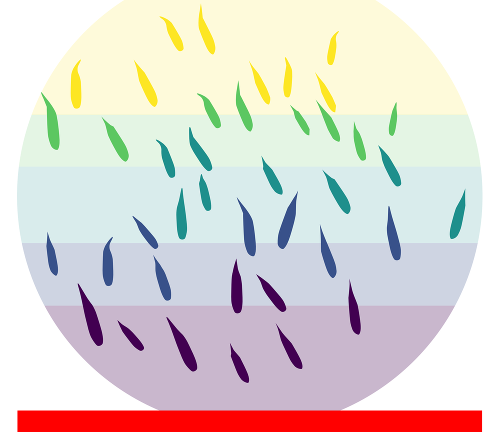


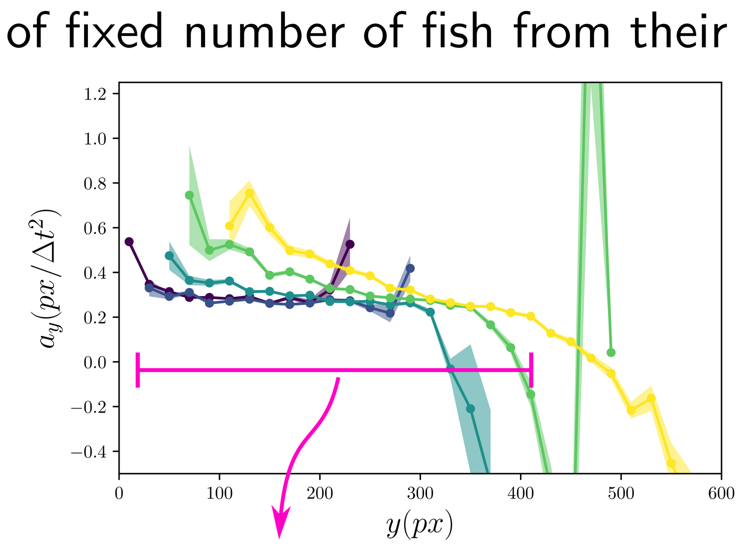
Conclusions

- Wall forces in a fish school are long-range, in contrast with experiments of one or two fish.
- We model trajectories of schooling fish and find the MSD matches the experimental trajectories.
- Manuscript in preparation.

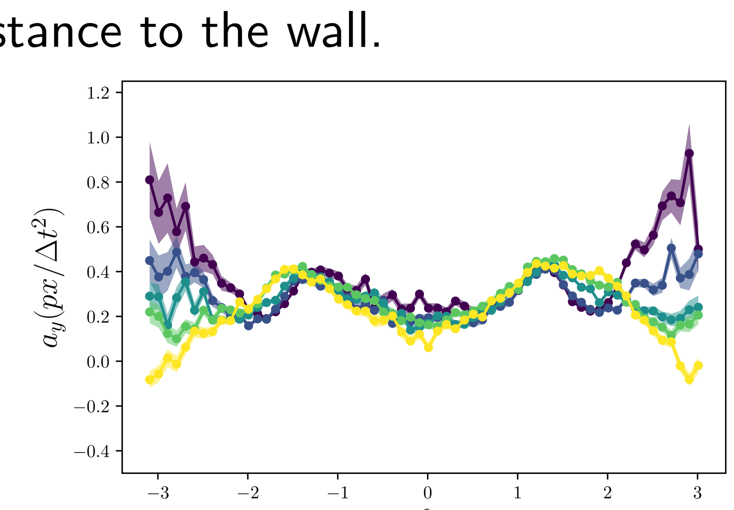
4. Structure of the interactions

We define topological layers of fixed number of fish from their distance to the wall.





The long range interactions observed in the school is caused by the transmission of information across layers.



Nearer layers feel a stronger repulsion when moving away from the wall (large angles).