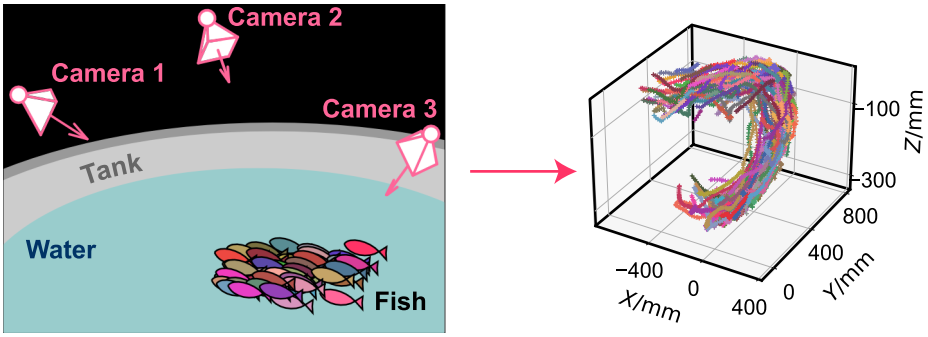
Just three fish form a school



Researchers at ESPCI Paris, together with physicists from Heinrich Heine University, Düsseldorf (Germany) and Bristol (UK), have investigated the swarming behavior of zebrafish. They located the swimming trajectories and analyzed them using methods of multi-particle physics. Interestingly, a large school of fish does not differ significantly from a very small group of three fish, whereas two fish move in a fundamentally different way. The research was published in the journal *Nature Communications* with the result "Three is a Crowd" in the title.

Can you count to three yet? For certain phenomena, three different numbers are indeed sufficient to characterize different states, such as the three musketeers, the three spatial dimensions, the three primary colors, etc. The question can also be posed slightly differently: from what number of participants do groups behave like a huge crowd? Researchers from Düsseldorf, Bristol and Paris have answered this question, at least for zebrafish. The astonishing result: the arrangement and movement patterns are similar to those of a large group from as few as three participants. However, these differ significantly from an isolated pair of two fish.

In an aquarium equipped with synchronized cameras, the researchers in Bristol reconstructed the three-dimensional swimming trajectories of zebrafish. These were systematically recorded for different group sizes, i.e. for groups of two, three, four and fifty fish. The organisation of the fish was then extracted from these. Various movement patterns occur: either the fish all swim in the same direction or they turn in circles together. If they move in the same direction, they can either swim next to each other or behind each other. An isolated pair of two fish prefers to swim one behind the other (i.e. one of them leads, the other follows), but three fish typically swim side by side (i.e. no one wants to be last). Such side-by-side swimming also characterizes a large school of fish.

What surprised the researchers was that if you mark a group of three in a large shoal, their behavior is very similar to an isolated group of three. If, on the other hand, you mark two neighbors from a shoal, you notice that they swim differently in the shoal than in an isolated group of two. This means that three fish practically form a shoal, but two are not enough.

Dr. C. Patrick Royall was awarded a Bessel Prize by the Alexander von Humboldt Foundation and has thus visited Heinrich Heine University and the Institute for Theoretical Physics II of Prof. Dr. Hartmut Löwen, his host, several times, as a result of which this joint research project was created and carried out. Professor Löwen comments: "It was a new challenge to apply traditional methods and concepts from the theory of fluids (such as pair and triplet correlations) to fish. These concepts originate from thermodynamic equilibrium, but a living school of fish is far away from equilibrium."

In addition to a basic classification of the many-body effects, the Düsseldorf contribution also consisted of a modeling and simulation of the fish trajectories by Dr. Alexandra Zampetaki, the first author of this study, who commented as follows: "We incorporated various input parameters into our model, which realistically simulated the swimming movement of the fish, and were thus able to confirm the astonishing result "three is a crowd".

This fascinatingly simple result only applies to zebrafish for now, but the concepts can also be applied to other examples of fauna. These include other schools of fish (such as goldfish and sardines), but also flocks of birds and insects (such as flying starlings and dancing mosquitoes). Finally, it would also be highly interesting to analyse and characterize the group behaviour of people, e.g. at parties or mass events. Only time will tell whether the simple limit of the number three will hold there, too.