Internships on

Wave-particle interactions at the macroscopic scale

Type: experimental and/or theoretical and/or numerical

Areas of Physics concerned:
fluid mechanics, complex systems, non-linear physics,
statistical mechanics, wave physics, foundations of quantum mechanics,

Host: CNR-Nanotec at the University of Calabria.
Place: Department of Physics at the University of Calabria.
Internship Responsible: **Giuseppe Pucci**, giuseppe.pucci@cnr.it, www.gpucci.net.
Period: to be decided in agreement with the student.
Internship languages: English and/or French and/or Italian

General objective: introduction to wave-driven particles at the macroscopic scale.

Specific objectives according to the type of internship chosen**:**
- experimental**:** set up of an experiment in fluid mechanics; use of 3D printer and laser cutter; data acquisition and processing using cameras and image analysis.
- numerical**:** understanding and use of a numerical code; data analysis.
- theoretical**:** understanding of an existing theoretical model; development of a new theoretical model.

The student will be introduced to wave-particle interactions on a macroscopic scale, a field of research that has attracted great interest and developed over the past two decades. In 2005, Y. Couder, E. Fort and collaborators in Paris discovered that a liquid droplet can propagate by bouncing off the waves it creates on the surface of a liquid subjected to vibration, giving rise to a walker [1] (fig.1a,b). A walker is a type of wave-particle association on a macroscopic scale that exhibits a number of analogies with quantum mechanics [2], including probability distributions (fig.1c) and orbit quantization, and prompts the question of **where the boundary between classical and quantum physics is**. In addition, this system makes it possible to explore the **collective behavior** of interacting particles via waves, particularly macroscopic spin lattices [3] (fig.1d).

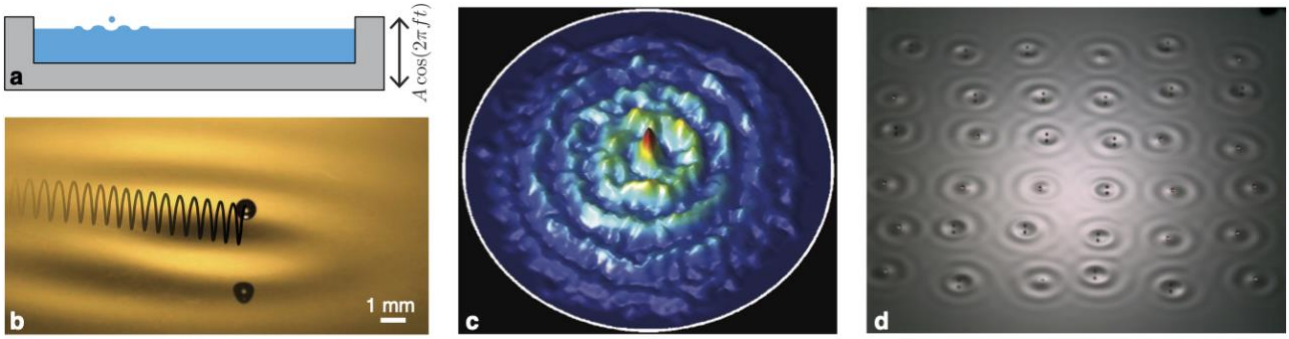

Fig. 1. (a) Schematic in side view of the experimental setup for the study of bouncing drops. (b) Experimental image of a walker. (c) Probability distribution of a walker in a circular cavity. (d) Spin lattice of walkers.

Recently, a new macroscopic wave-particle coupling system was discovered at Brown University, in which an asymmetric solid particle is guided by the waves it generates on the surface of a vibrating liquid, giving rise to a surfer [4] (fig.2a,b). Surfers are much more versatile than walkers experimentally (fig.2c,d) and thus allow wave-particle interactions to be studied in a greater number of configurations.

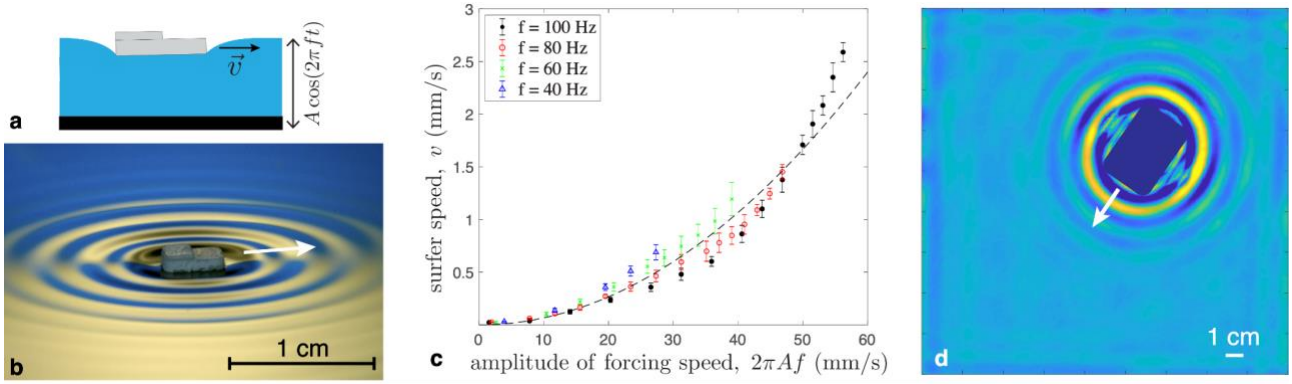

Fig.2. (a) Schematic in side view of a surfer and (b) experimental image. (c) Velocity of a surfer as a function of the speed amplitude forcing the liquid vertically. (d) Experimental reconstruction of the wave field of a surfer.

Proposed internships

Walker and surfer allow for countless experimental, theoretical and numerical studies in the areas of:
1) fluid mechanics at the fluid interface and surface waves;
2) the fundamentals of quantum mechanics and its relation to classical physics;
3) the statistical mechanics of complex wave-interacting systems;
4) wave phenomena and analogies with wave optics.

The specific internship topic will be chosen in agreement with the student.

Possible collaborations (depending on the topic chosen):
- Prof. Anand Oza, Department of Mathematical Sciences, New Jersey Institute of Technology, USA (link).
- Dr. Antonin Eddi, Laboratoire PMMH - ESPCI Paris, France (link).
- Prof. Daniel M. Harris, Brown University, USA (link).
- Prof. Pedro J. Sáenz, University of North Carolina at Chapel Hill, USA (link).
- Dr. Andrea Puglisi, Istituto dei Sistemi Complessi (ISC - CNR), Roma (link).

References

[1] Y. Couder, S. Protière, E. Fort, and A. Boudaoud, Walking and Orbiting Droplets, *Nature* **437**, 208 (2005).
[2] J. W. M. Bush and A. U. Oza. Hydrodynamic quantum analogs. *Rep. Prog. Phys.* **84**, 017001 (2020).
[3] P. J. Sáenz, G. Pucci, S. E. Turton, A. Goujon, R. R. Rosales, J. Dunkel, and J. W. M. Bush, Emergent Order in Hydrodynamic Spin Lattices, *Nature* **596**, 58 (2021).
[4] I. Ho*, G. Pucci*, A. U. Oza, and D. M. Harris, Capillary Surfers: Wave-Driven Particles at a Vibrating Fluid Interface, *Phys. Rev. Fluids* **8**, L112001 (2023).

Videos

The pilot-wave dynamics of walking droplets
Spin lattices of walking droplets
Capillary surfers
Sync or swim