# Macroscopic pilot-wave dynamics in density-stratified fluids

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Inspired by bouncing drop experiments that revealed how macroscopic systems can exhibit wave-particle properties previously thought to be exclusive to quantum systems [1,2,3], we introduce here a new wave-particle system based on internal gravity waves propagating in density- stratified fluids. Recent experiments [4] on particles (called ludions) oscillating in such a fluid medium suggest that wave-particle interactions can induce symmetry breaking, leading to spontaneous self-propulsion of the particle in the horizontal plane. Here, we propose a minimal hydrodynamic theory showing that this instability can be explained by a Doppler force emerging from interactions between the ludion and its own wave field (see Figure 1-a). We validate our theoretical predictions using direct numerical simulations, which confirm that the growth of the instability is determined by the particle oscillation amplitude. In wall-bounded domains, reflections of the internal waves create a Casimir-like potential that rapidly develops and constrains the particle motion. Despite the presence of the Doppler force, this potential governs the ludion long-term dynamics, leading to capture in fixed points or chaotic attractors near the potential wells (see Figure 1-b). Our findings establish the ludion as a novel hydrodynamic pilot-wave system, offering a new platform for exploring macroscopic wave-particle duality, particularly in three-dimensional configurations.

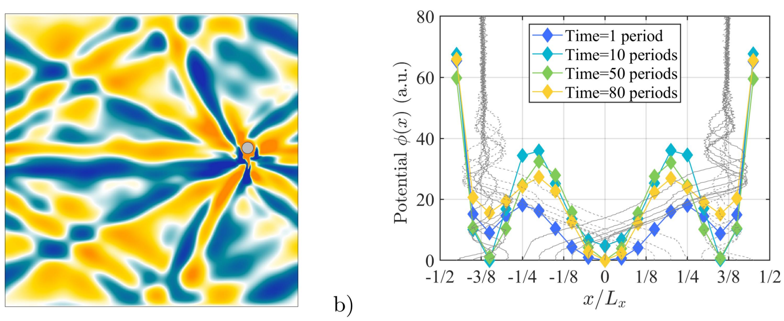


**Figure 1.** a) Snapshot from a numerical simulation using the Lattice Boltzmann Method [5] of a self-propelled ludion in a density-stratified fluid domain (here in a 2D periodic domain with a vertical oscillation frequency half the Buoyancy frequency). The Doppler effect breaks the forward/backward symmetry by modifying the angles of the internal gravity wave vectors and thus leads to the ludion self-propulsion, here towards the right. b) In a bounded domain, the waves reflect off the walls and create a Casimir-like potential capable of trapping the ludion, regardless of its original location along the horizontal direction.

## Références

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