Imaging and Mapping of Quantum-Like Behavior in a Hydrodynamic System

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Abstract

A pilot-wave hydrodynamic system consists of a small droplet of silicone oil that is self-propelled across a vibrating bath of the same liquid. Bouncing vertical motion and "walking" horizontal motion of the droplet can be achieved with careful control over the frequency and amplitude of the oil bath oscillation. The observed “walking” motion is due to the interaction of the droplet with the waves that it generates as it bounces off of the vibrating liquid surface. This system provides a compelling macroscopic analog to the Bohmian pilot-wave interpretation of quantum mechanics. We present results from our hydrodynamic system, including efforts to observe single-particle interference, diffraction, and wave-guide behavior.

References

Single-Particle Diffraction: Y. Couder and E. Fort, “Single-particle diffraction and interference at a macroscopic scale,” Physical Review Letters 97, 154101 (2006).
Interference in a Corral: D. M. Harris, J. Moukhtar, E. Fort, Y. Couder, and J. W. M. Bush, “Wavelike statistics from pilot-wave dynamics in a circular corral,” Physical Review E 88, 011001(R) (2013).
Double-Slit Interference: A. Andersen, J. Madsen, C. Reichelt, S. R. Ahl, B. Lautrup, C. Ellegaard, M. T. Levinsen, and T. Bohr, “Double-slit experiment with single wave-driven particles and its relation to quantum mechanics,” Physical Review E 92, 013006 (2005).
Time Reversal and Information: S. Perrard, E. Fort, and Y. Couder, “Wave-based Turing machine: time reversal and information erasing,” Physical Review Letters 117, 094502 (2016).

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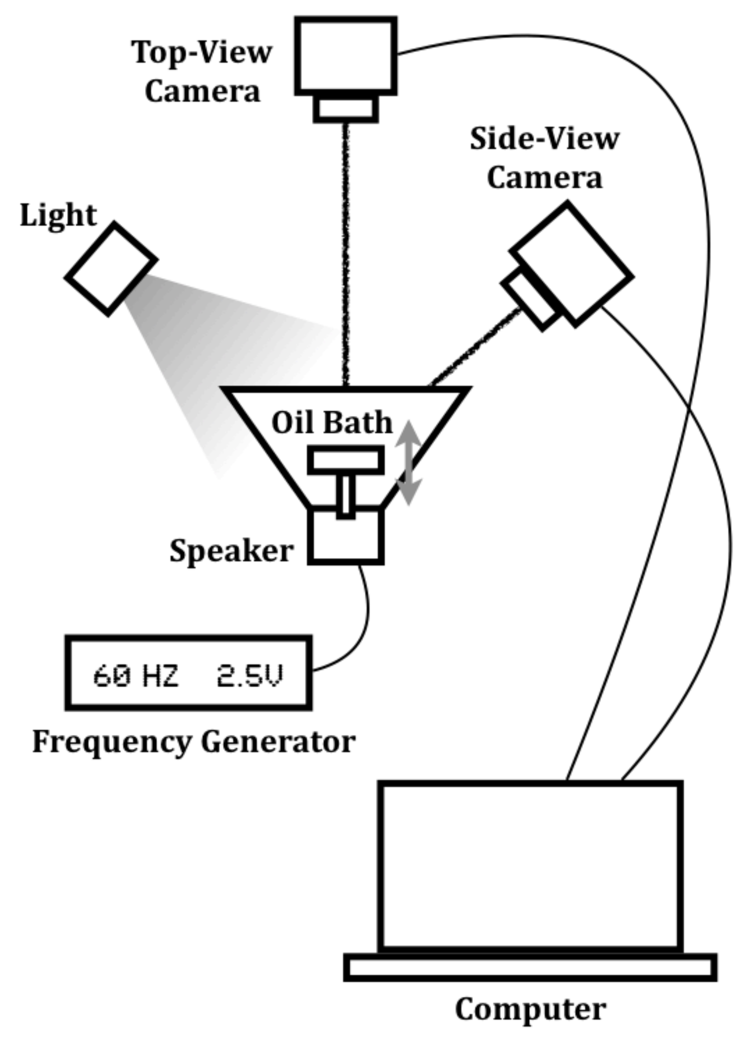
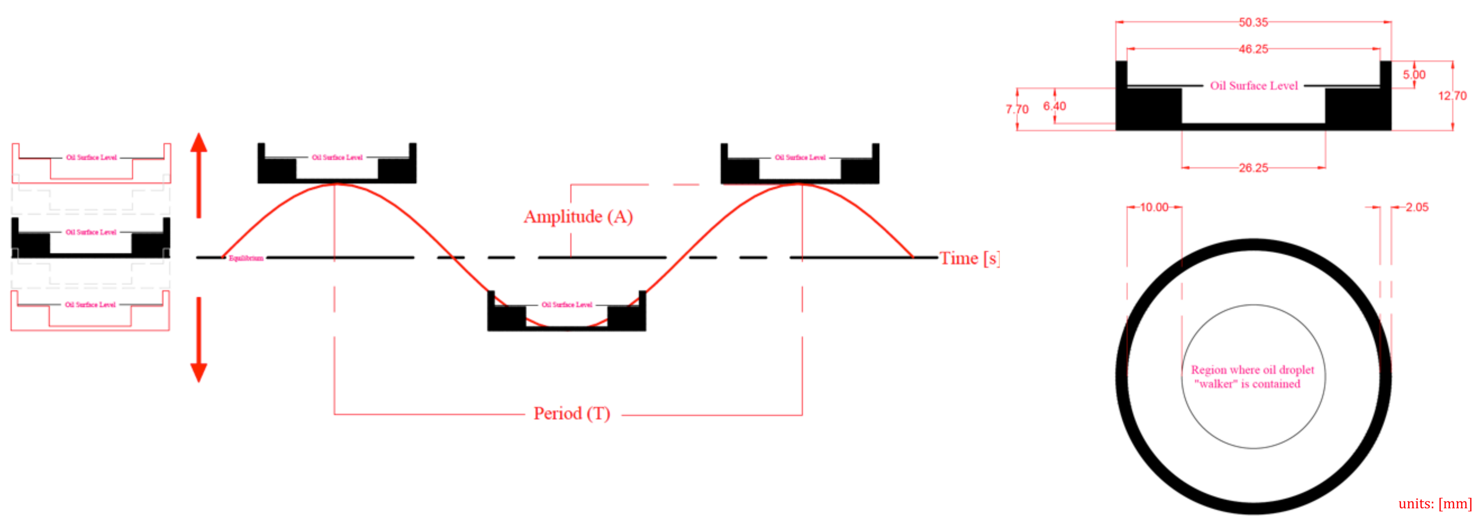
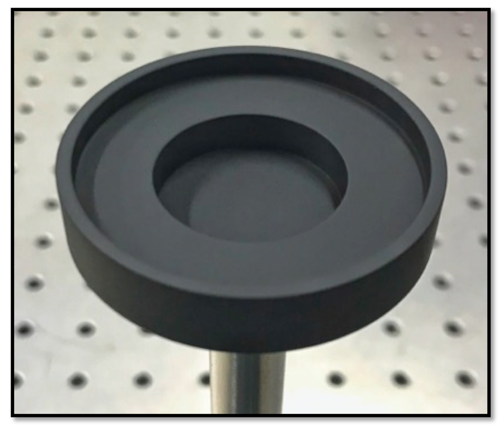
Home-Built Shaker System



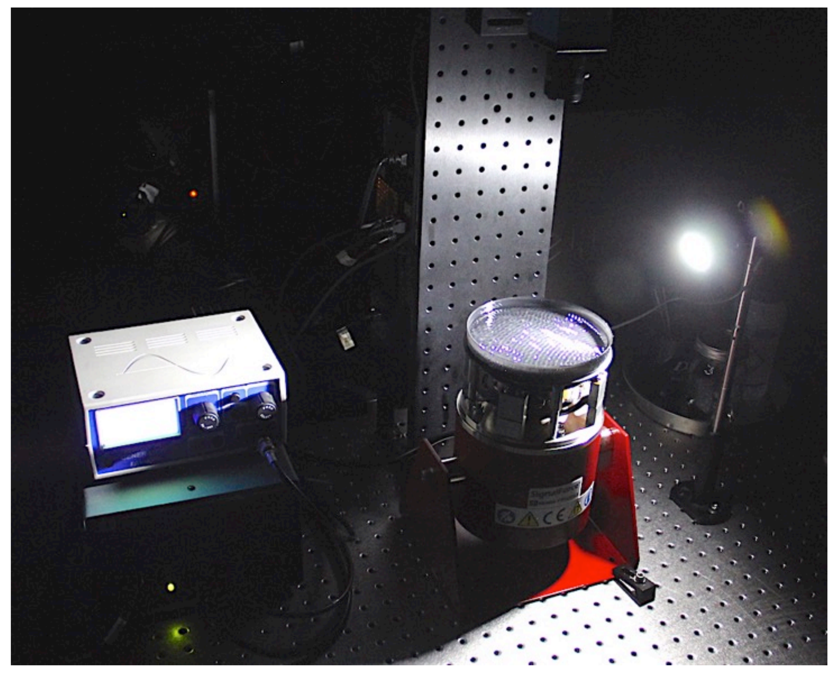


Quantum Corral

An oil bath was custom machined out of solid aluminum and mounted to a frequency- and amplitude-controlled speaker. It was painted matte black to limit reflections that would interfere with the droplet tracking software. The bath was filled with silicone oil to a level just above the outer flat region, enabling the bouncing droplet to be contained in the inner region. This one-inch diameter region readily supports standing waves at a few discrete frequencies.



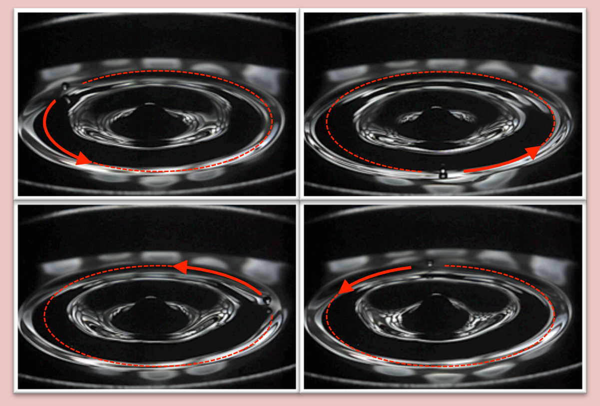
Commercial Shaker System



Modular Oil Bath Geometries

A six-inch diameter dish was affixed to a steel backing plate and mounted to a commercial permanent magnet shaker (Data Physics Signal Force GW-V20). The large bath area allows for excellent free-particle motion, and will be used to test pilot-wave dynamics. Magnets can be affixed to the dish just below the oil surface to create various diffraction, interference, and waveguide geometries.

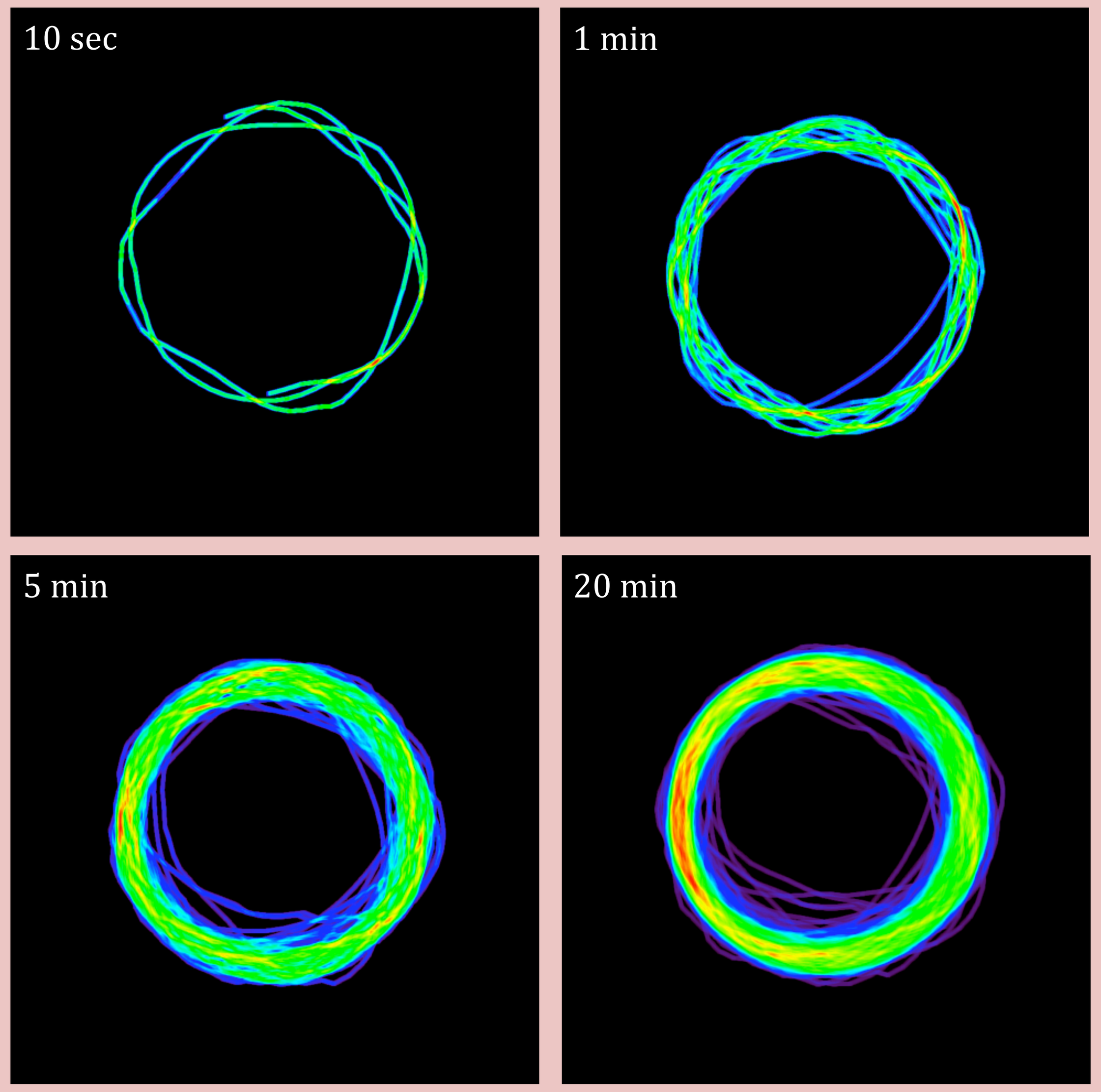
Standing Waves at High Amplitudes



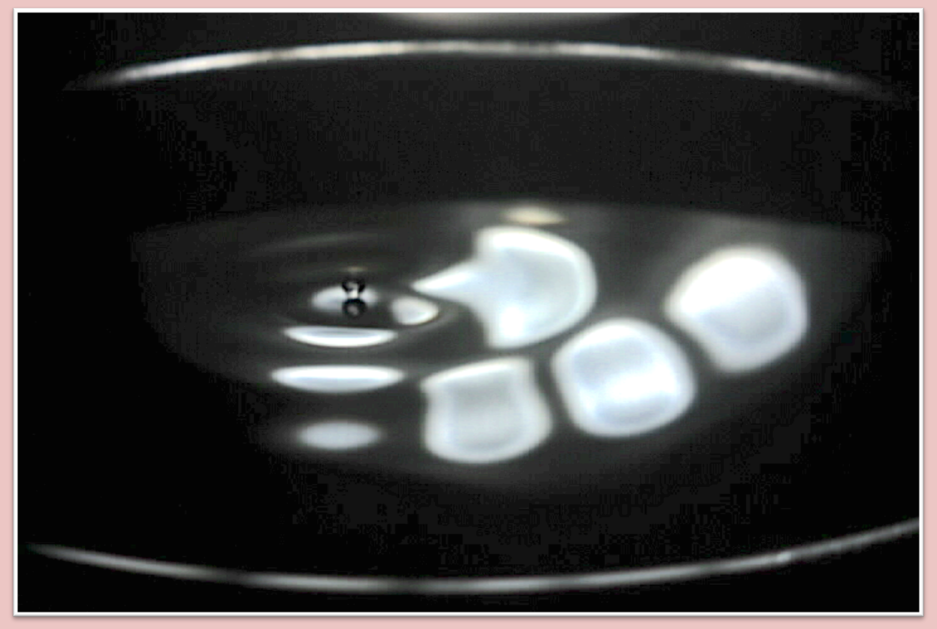
At high oscillation amplitudes, the surface of the oil exhibits significant modulation. By tuning the driving frequency, stable spatial modes can be observed as standing waves. A bouncing droplet in this regime will remain confined within a circular node. The motion is predictable and the pattern generated is the same for all time scales. Frames captured from a side-view video (above) show the circular droplet motion. The top-view droplet tracking system generates “heat maps” of the droplet position for different time scales (below). Bright colors indicate higher droplet “probability density” (due to slower motion or repeated occurrence at a given location).

Droplet Heat Map Color Scale

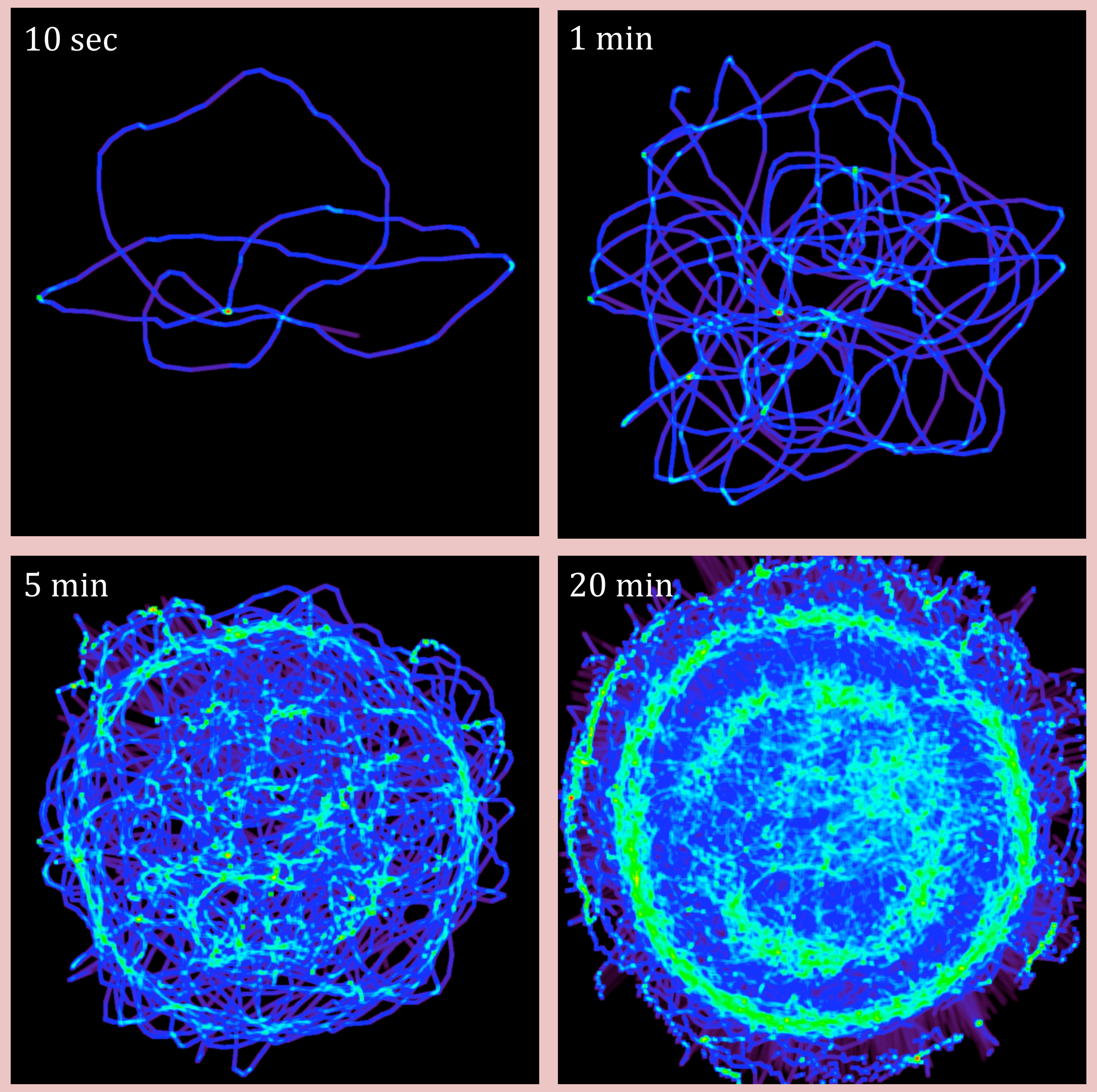
← low — Probability Density — high →



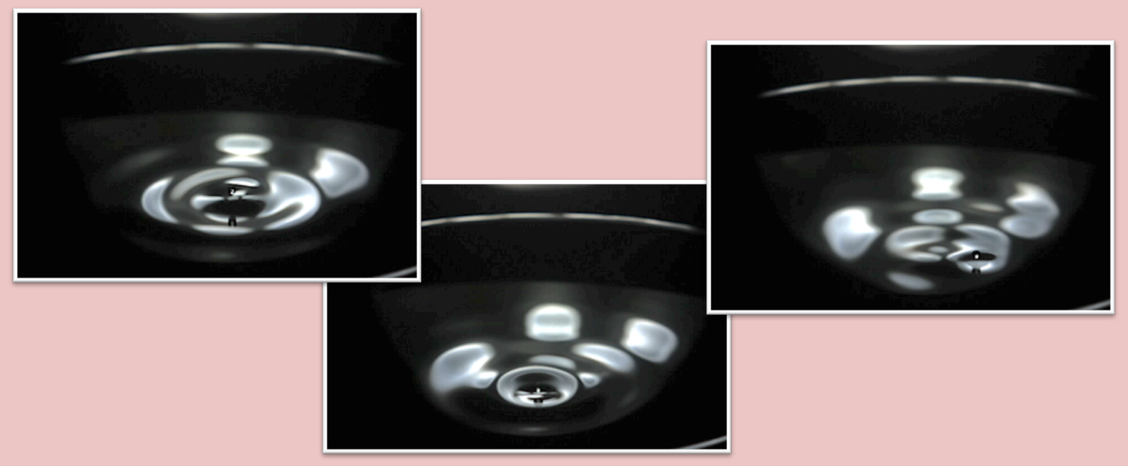
Intermediate Regime



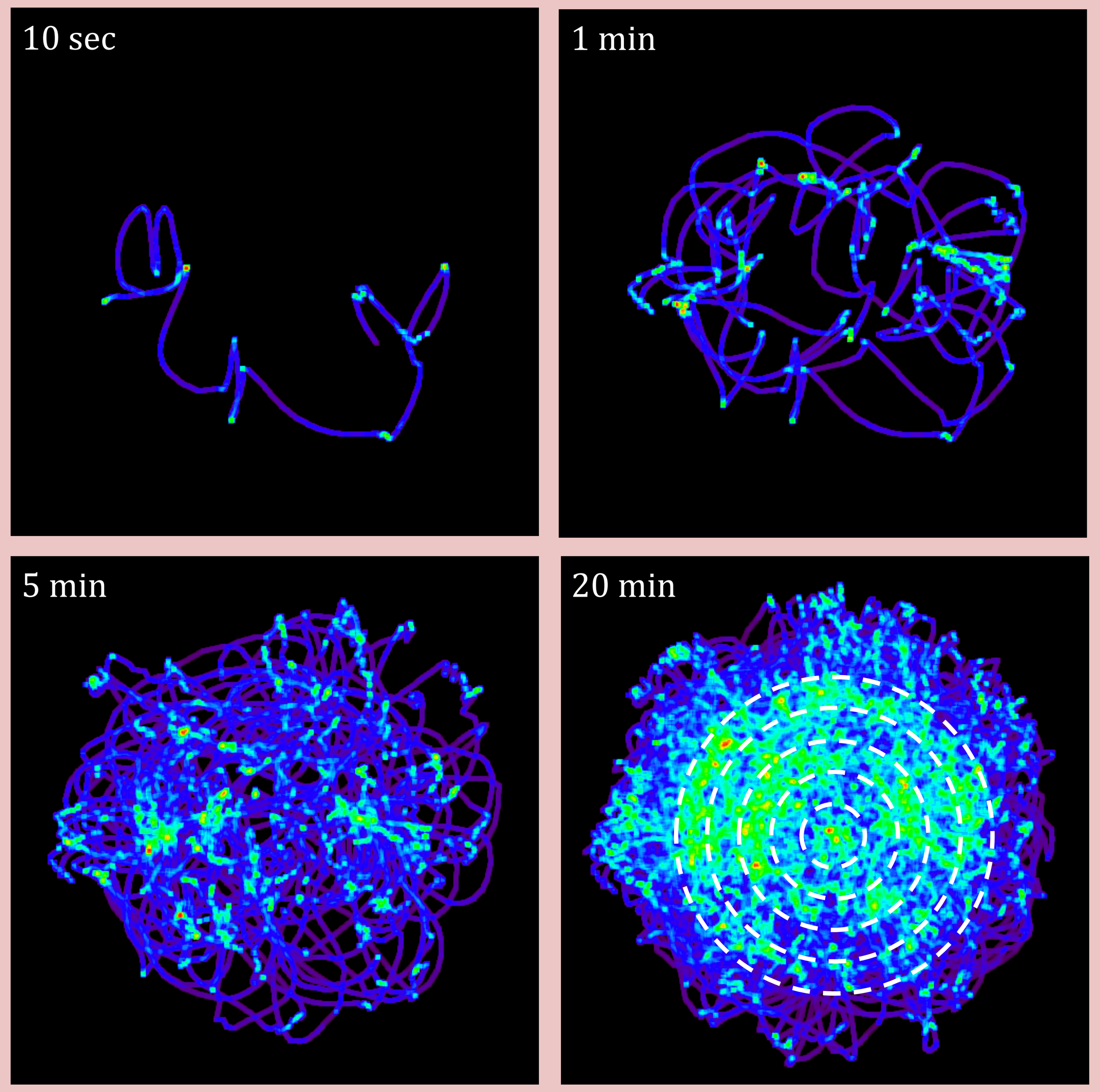
As the oscillation amplitude is reduced, the height of the surface waves inside the oil bath will decrease until they are barely visible (above). As a result, the waves generated by the droplet bouncing on the oil surface will have a greater impact on its subsequent motion. The patterns generated by the motion of the droplet (below) evolve significantly over time, showing evidence of the self-propelled (seemingly random) droplet motion as well as the influence of the (highly structured) standing waves.



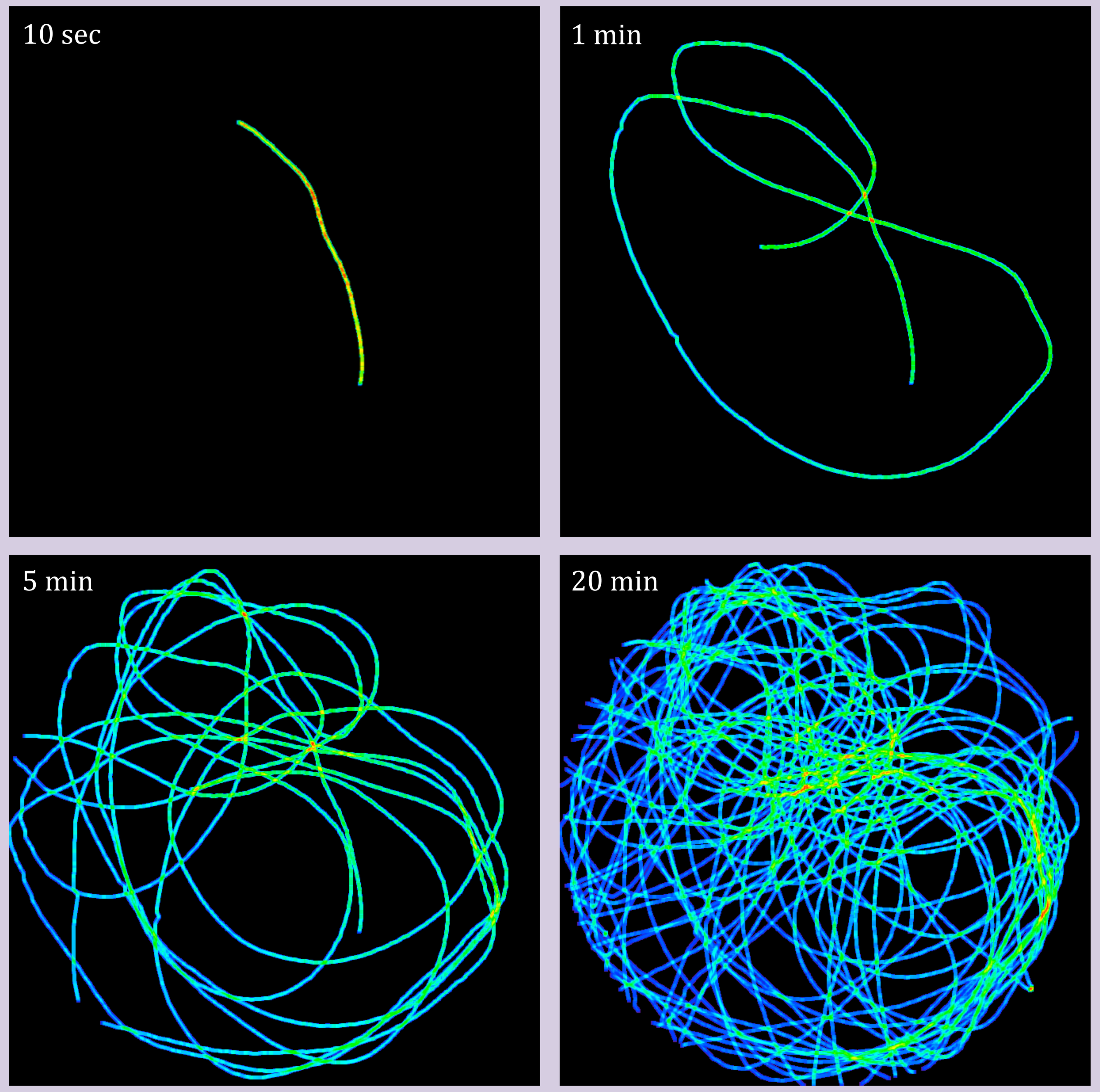
Walkers and Interference Effects



Within a narrow range of amplitudes for a given frequency, the self-propelled droplets (“walkers”) wander across a completely flat oil surface (above). The droplet motion is governed entirely by the waves that the droplet itself creates. For short time scales, this motion exhibits apparently random behavior (below), but for longer times, interference patterns emerge that are completely different from the standing wave patterns generated at higher oscillation amplitudes. These patterns are due to the interference of the droplet *with itself!* This behavior is analogous to a single electron trapped in a “quantum corral.” The beginnings of a central peak surround by a circular fringe are observed below (denoted by the dashed lines). Ongoing improvements to our speaker and shaker systems will improve the quality of the observed interference patterns.



Free-Particle Trajectories



Diffraction & Wave Guides