Whispering gallery mode yields intense acoustic streaming in sessile droplets

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Acoustic streaming is a steady flow created by intense sound waves. It is an important phenomenon in digital microfluidics to expedite the mixing of sessile droplets. A typical configuration is to send trains of surface acoustic waves (SAW) beneath the droplet. These waves then radiate in the fluid and generate acoustic streaming. Despite the practical importance of this phenomenon, the detailed process between the radiation of the SAW and the acoustic streaming is unclear and most simulations rely on gross assumptions about the acoustic field in the droplet. In this study, we develop a first-principle numerical model to understand the relation between the radiated wave, the acoustic streaming force and the resulting flow field.

According to our simulations, the flow is driven by two types of ultrasonic caustics (i) volume caustics reflected from the droplet surface similarly to a concave mirror (not shown here) and (ii) surface caustics analog to a whispering gallery mode shown in figure 1.A. Remarkably, the surface caustics describe periodic orbits along the droplet surface and therefore remain coherent even after long fly times, whereas volume caustics become increasingly chaotic. Once the force term identified, we computed the flow pattern and compared it to experimental data (Fig. 1B). The good agreement supports that the acoustic field is accurately captured by the numerical model. Furthermore, the caustics physically correspond to the points where the flow is the most intense. Eventually, by tuning the liquid viscosity, we were able to vary the relative importance of surface and volume caustics: at low viscosity, surface caustics efficiently resonate and create a strong quadripolar flow pattern (figure 1.B) whereas at high viscosity the volume caustics are stronger and yield a dipolar flow pattern (not shown here).

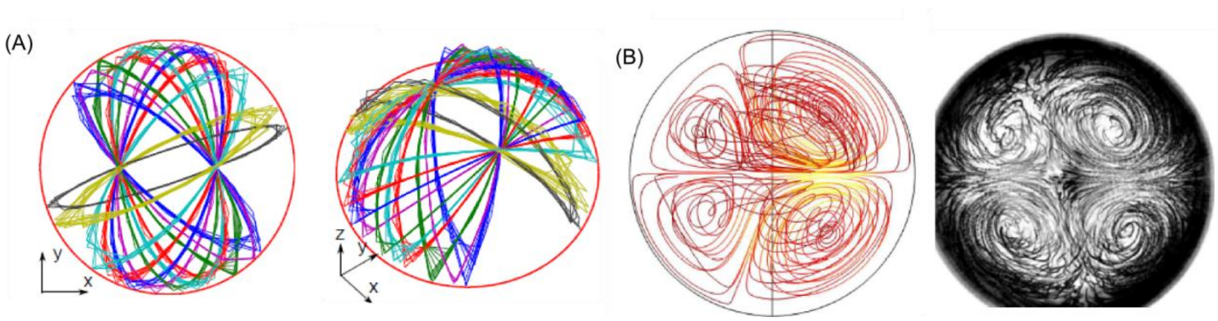

Figure 1: (A) Geometrical acoustic interpretation of the acoustic streaming in sessile droplets. The whispering gallery mode is represented here. The rays propagate along periodic orbits guided by the droplet surface. (B) Hydrodynamic flow (numerical result on the left and experimental PIV streamlines on the right).

In conclusion, we have developed first-principle algorithm to compute the acoustic field and acoustic streaming in sessile droplets. It unveils for the first time the existence of powerful caustics that concentrate most of the acoustic power and generate the streaming flow. This study paves the way to understand more complicated acousto-fluidic phenomena such as droplet displacement or atomization.