WEEK 8

Article: Mahkam *et.al.*, A multiorifice acoustic microrobot for boundaryfree multimodal 3D swimming, *PNAS*, 2025.

QUESTIONS 8B

1. Why do very small (10 μm) or very large (100 μm) microrobots perform worse than those of intermediate size? How does changing the microbubble diameter influence the resonance frequency and subsequently affect the acoustic streaming patterns around the microrobot? The authors state that reducing bubble size causes the active frequency region to broaden and increases the number of responsive frequencies. Could you clarify the physical mechanisms behind this?

2. How do the streaming and radiation forces work together to move the microrobots around, and is it possible to tweak that balance to control their direction? Given that in low-viscosity fluids the robot can swim in four distinct acoustic modes—helix-like, linear translational, spinning, and rotational—could one steer its trajectory by superimposing or sequencing the driving frequencies that selectively activate these different modes? Could non-sinusoidal or pulsed signals unlock faster or more efficient switching?

3. The microrobots consist of a shell surrounding a trapped bubble. I would expect the bubble to escape from the shell due to buoyancy forces. Does the size and shape of the orifice influence the entrapment? What shell thickness to orifice size ratio would optimize the trade-off between bubble stability and propulsion efficiency in non-Newtonian fluids? In Figure 1C, the orifices exhibit an arc-like, tangent shape rather than a circular design. What are the specific physical or flow dynamic advantages of this arc-like geometry?

4. In robots with multiple orifices of different sizes, each resonates at a distinct frequency. How does the superposition of multiple acoustic streaming patterns across orifices create constructive or destructive interference in propulsion? Can destructive or constructive interference between flows lead to instability or degraded maneuverability? Could there be an optimal spacing or firing sequence that minimizes crosstalk between jets? Could spectral control allow tailored flow fields?