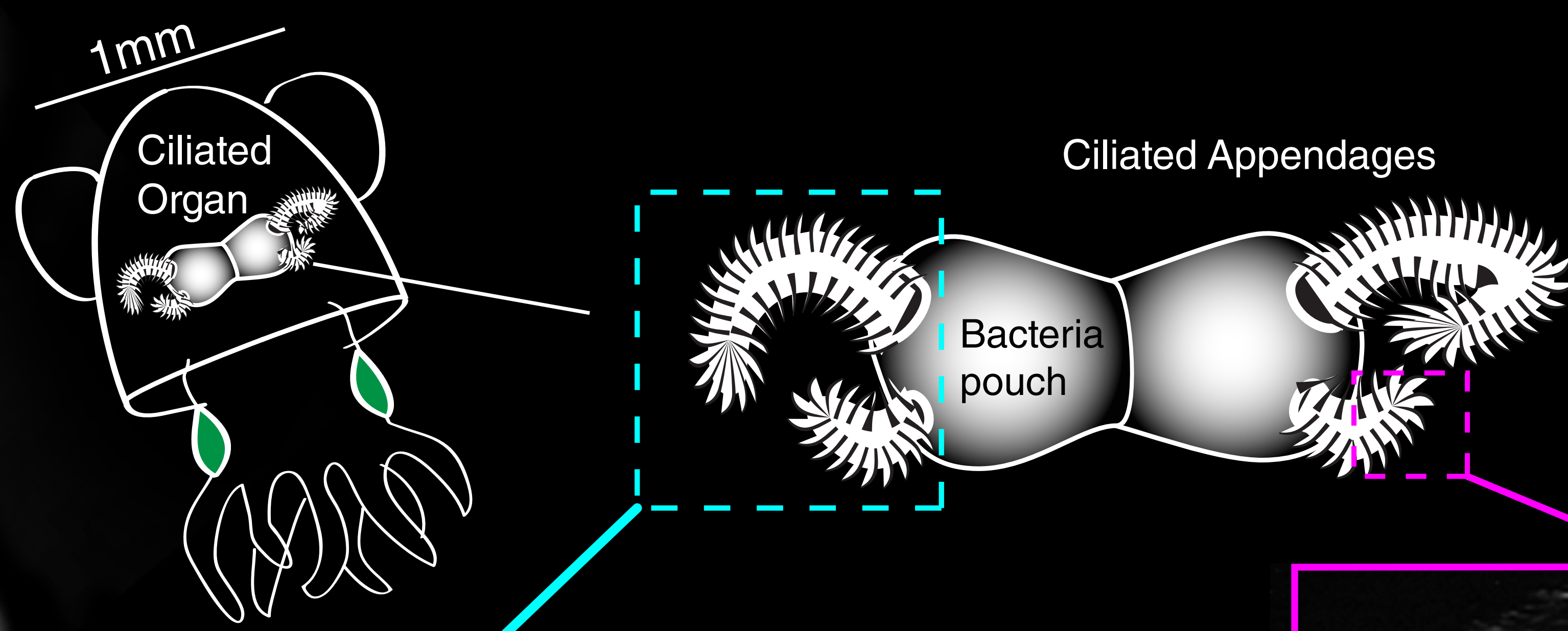


The Hawaiian Bobtail Squid has an internal ciliated organ that captures and harbors beneficial bacteria. Here we visualize the cilia-powered viscous streaming on the organ's surface that assists at isolating bacteria-sized particles from the ambient flow.

Cilia-powered particle streaming

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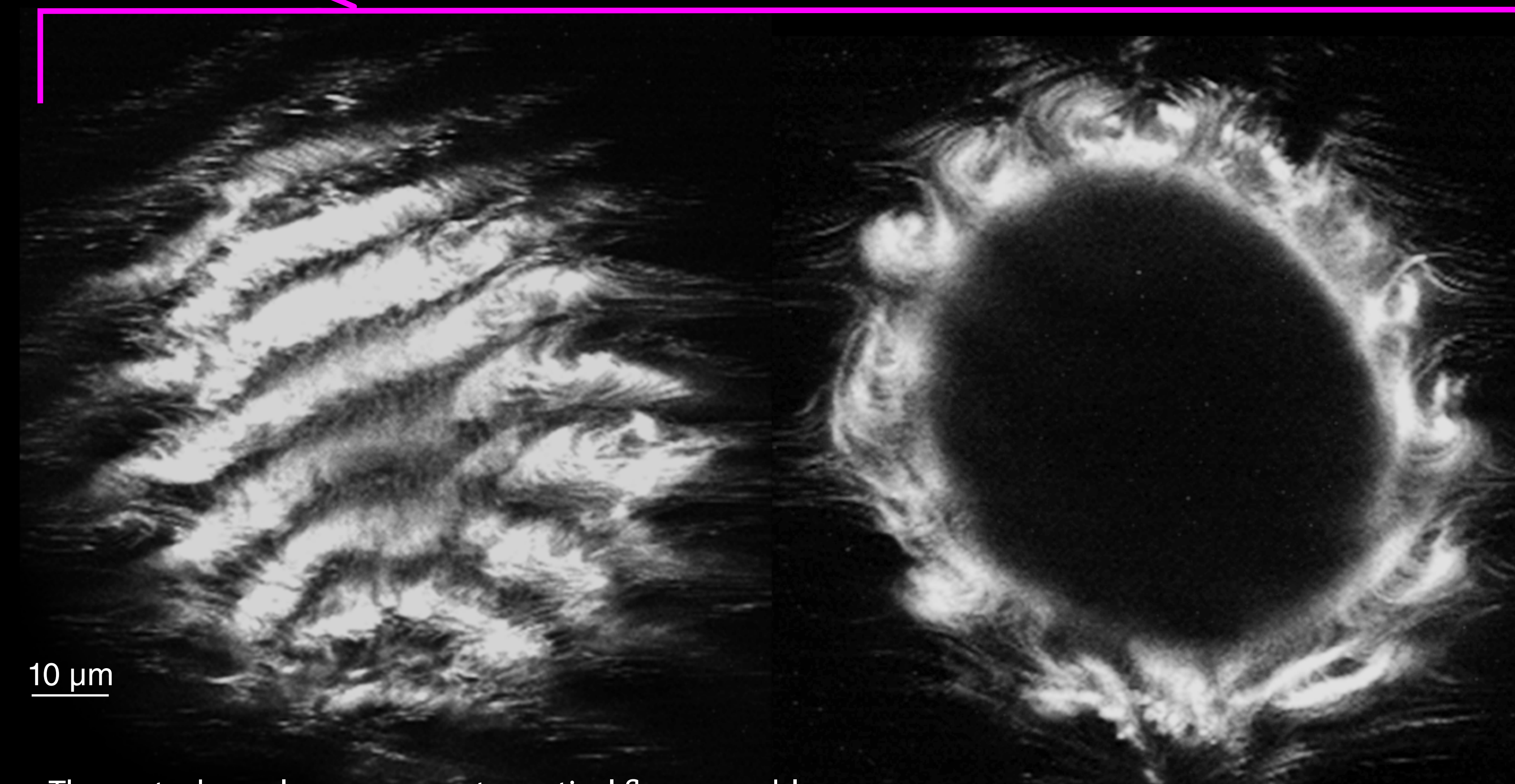
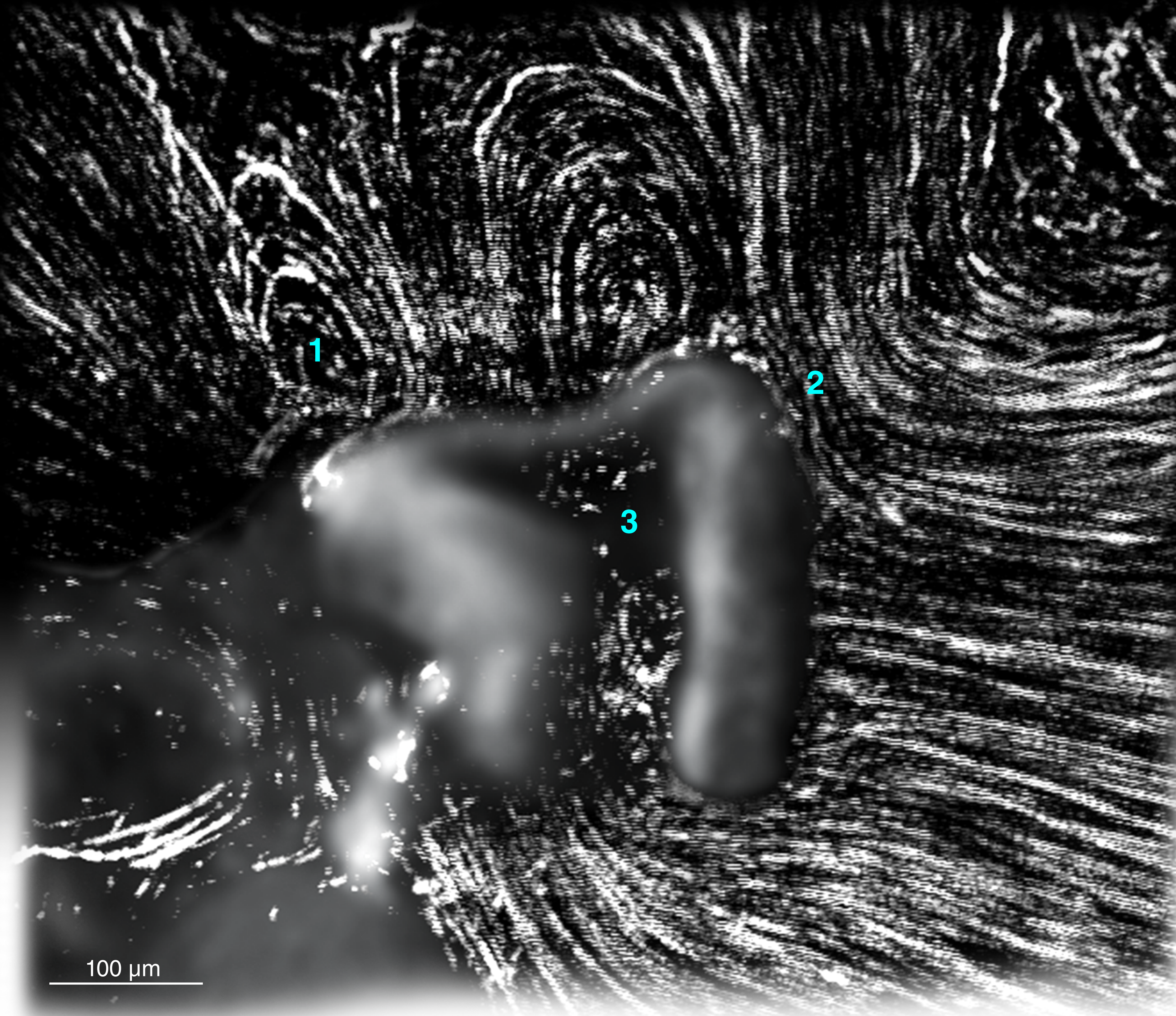
Close up on cilia-powered particle streaming

Viscous streaming is driven by surface oscillations. On ciliated surfaces, quasi-oscillatory ripples are achieved by spatiotemporal coordination of ciliary beating: Stroke phases of neighboring cilia are slightly shifted, resulting in periodic waves whose crests and troughs are formed by cilia in the effective and recovery stroke, respectively. These so-called metachronal waves travel across the surface, as visualized by high-speed camera snapshots (left: top view; right: cross-section).

A look at the entire cilia-generated flow field

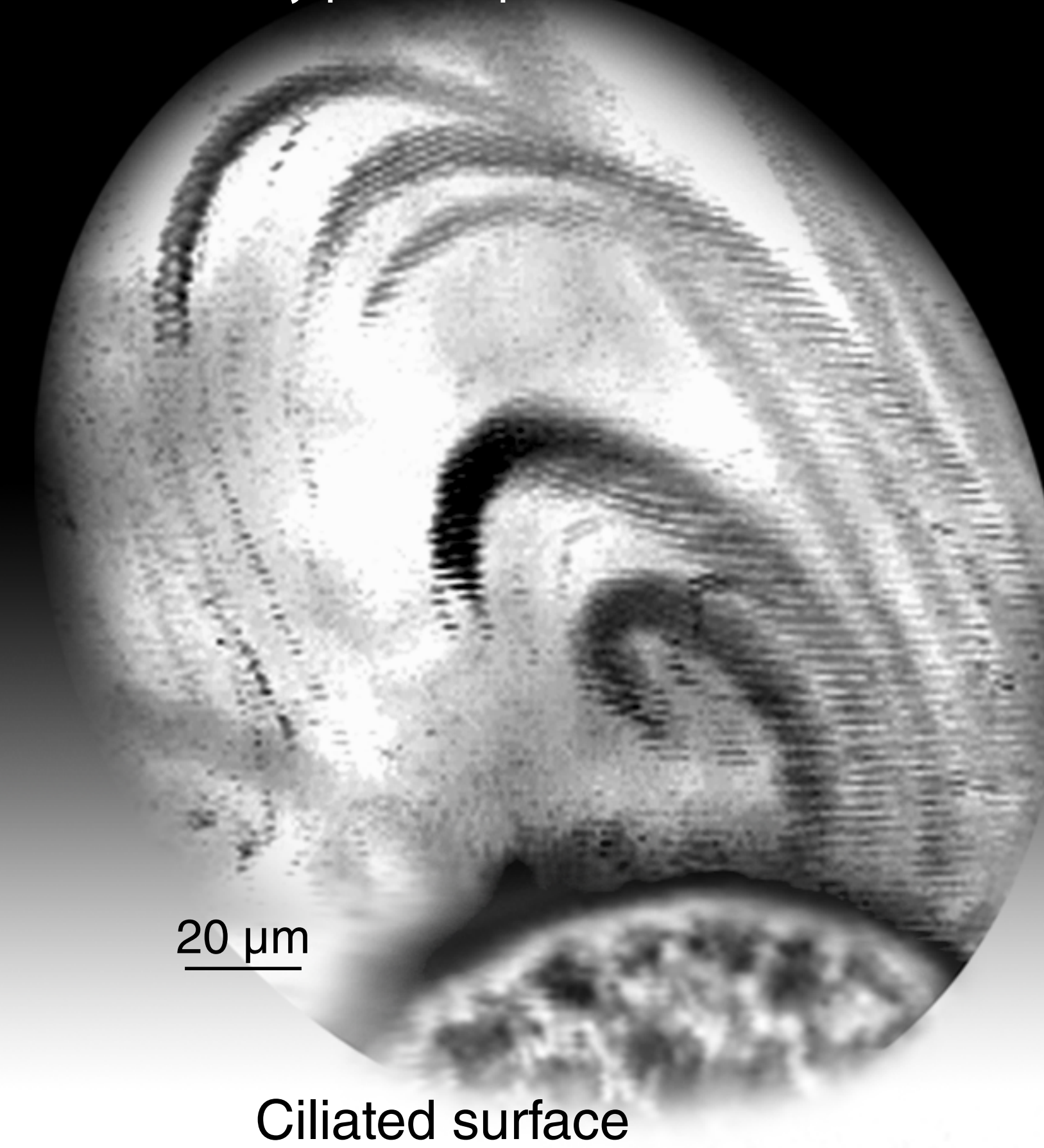
Cilia kinematics and surface topology interact to create a complex flow pattern around the ciliated appendages, as visualized by particle path lines. This flow achieves

- (1) sorting of bacteria-sized particles through viscous streaming
- (2) strong self-cleansing currents
- (3) bacteria accumulation in between the appendages through flow stagnation

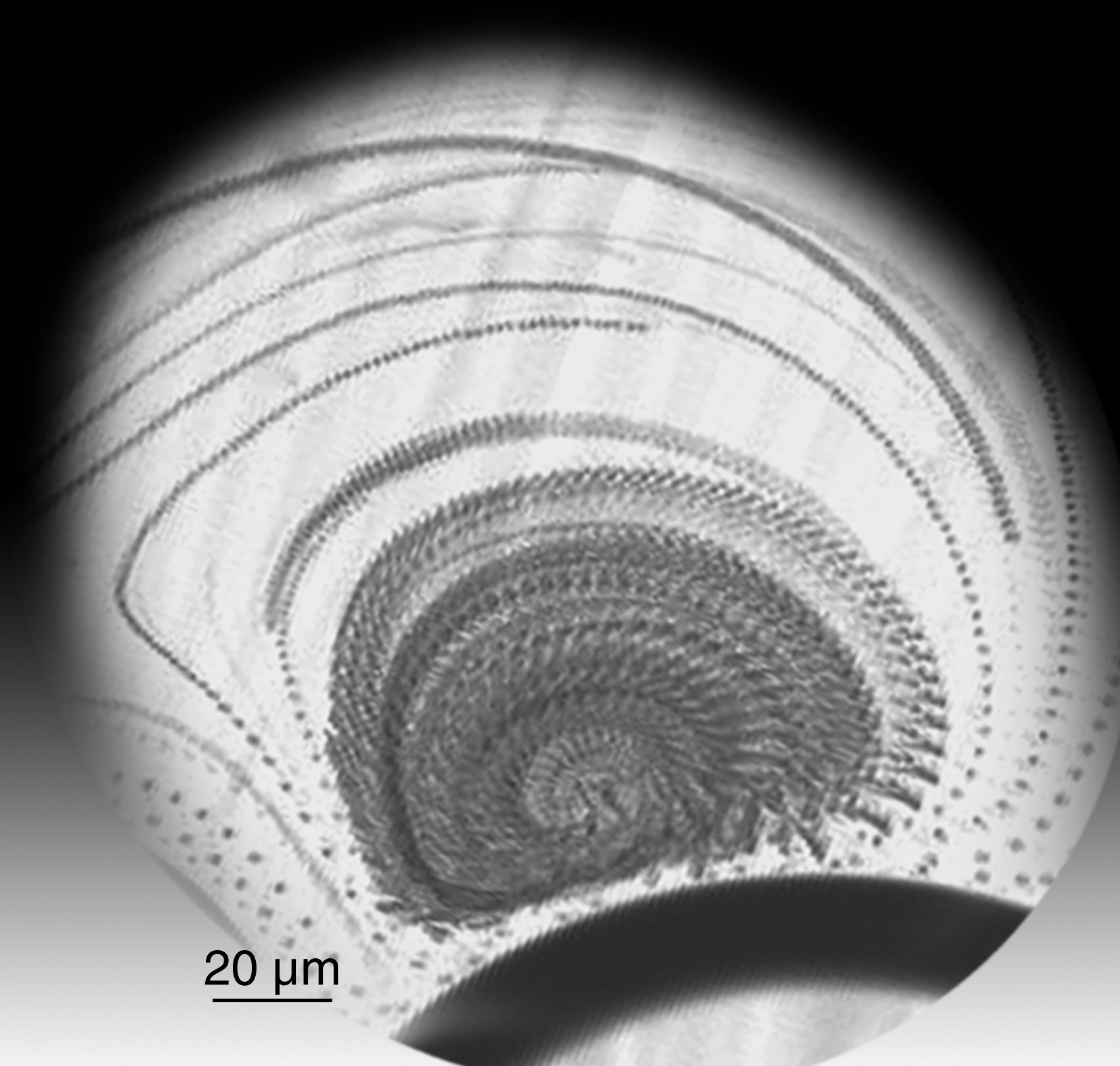


The metachronal wave generate vortical flows capable of accumulating particles: some (larger) particles cross streamlines and are diverted to the center whereas others (smaller) particles follow an outer trajectory, as visualized by particle path lines.

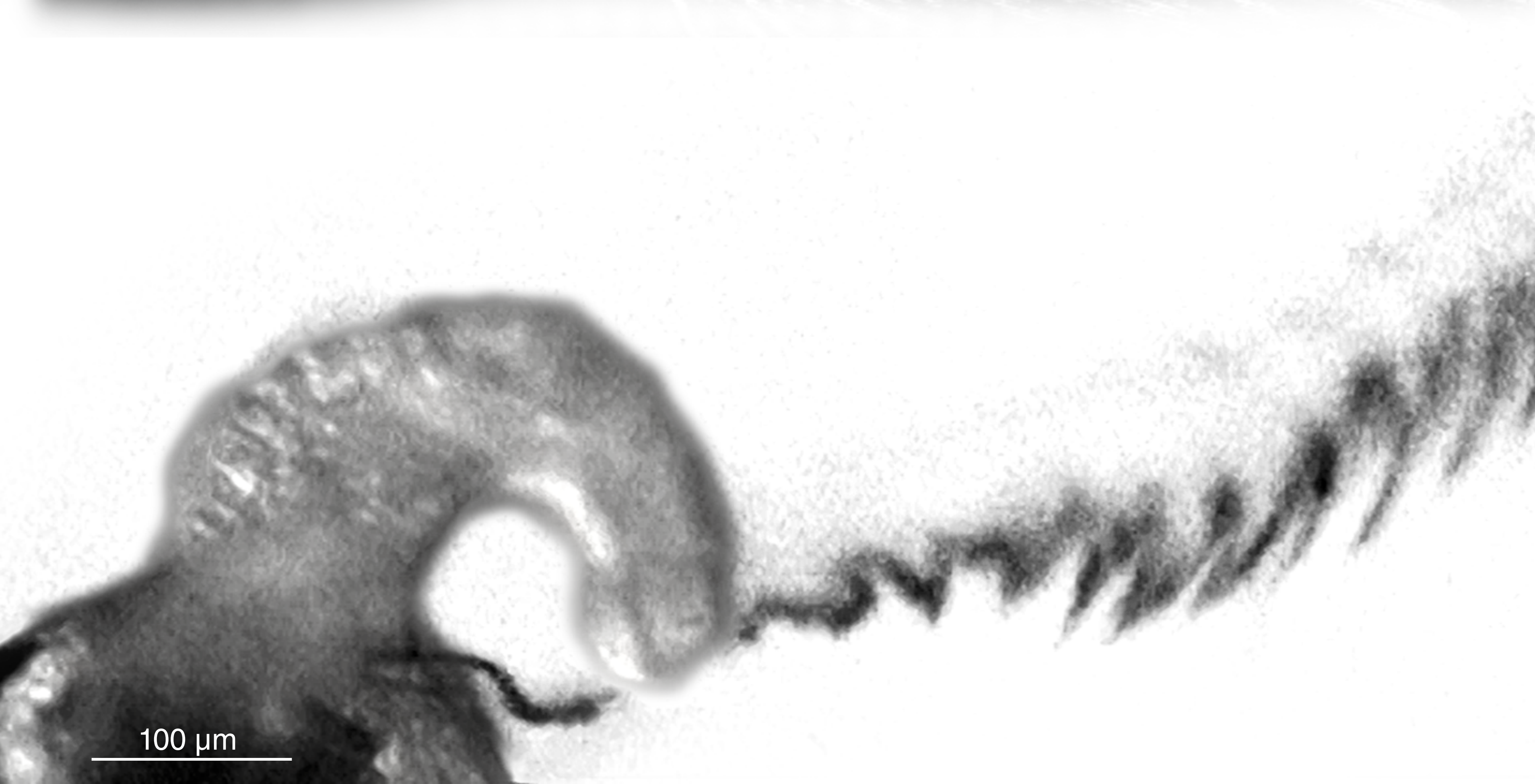
This streaming function can be produced with other oscillating surfaces at low Reynolds numbers, such as vibrating micro air bubbles in liquid.



Ciliated surface



Micro air bubble



The surface "oscillation" generated by the metachronal waves can be visualized using streak lines. Here, the ciliated organ, which contains squid ink, was pierced to release a thin line of ink tracing the cilia-generated flow.

See the movie at <http://goo.gl/KZCgOG> or scan this barcode

