Directed Transport and Current Reversal of Active Colloids under Traveling Wave Illumination

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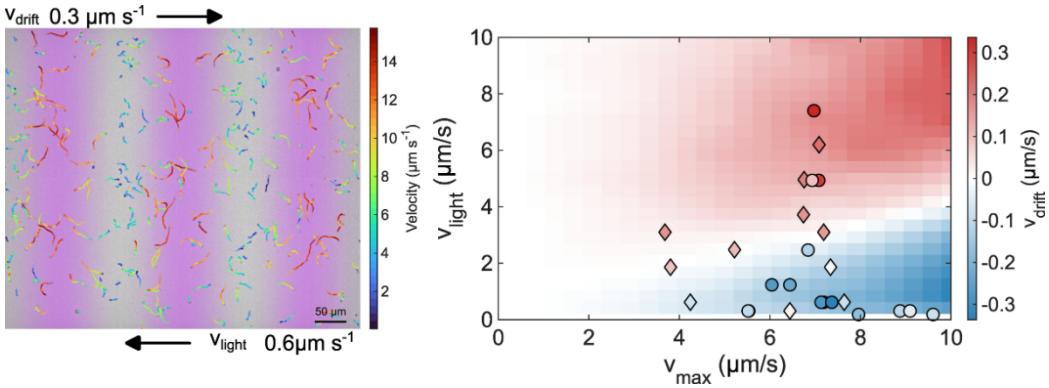
Synthetic active colloids offer a versatile platform to engineer directed transport through spatiotemporal control of motility. In recent work, we demonstrated that silica–titania Janus microswimmers driven by Induced-Charge Electrophoresis (ICEP) can autonomously adapt their propulsion speed through material-encoded sensory delays, whereby photoconductive titania caps couple particle velocity to local UV illumination intensity with a finite response time [1]. These sensory delays were shown to reshape steady-state density distributions and enhance localization under patterned illumination.
Here, we extend this framework to traveling wave activity modulation, where a periodic illumination pattern is translated at a controlled phase velocity across the sample. This dynamical protocol induces net particle transport whose direction and magnitude depend on the interplay between wave velocity, particle swim speed, and sensory delay. When wave and particle velocities are well-matched, particles tend to drift co-propagating with the wave; at mismatched velocities, transport can reverse. Sensory delays introduce a phase lag between illumination and velocity adaptation that further modulates the transport direction. These findings suggest that traveling wave illumination provides a non-contact route to directed transport and velocity-based sorting in active colloidal systems, and highlight sensory delay as a key parameter linking particle-level temporal response to emergent transport behavior.

Keywords:
photoresponsive microswimmers, motility control, colloidal transport



Directed transport of active colloids. (Left) Photoresponsive Janus microswimmers under moving sinusoidal UV illumination, trajectories color-coded by velocity. (Right) Net drift velocity vs. active and pattern speed, experiments (symbols) and simulations.

References:

[1] Ueli Töpfer. Maximilian R. Bailey. Sa njay Schreiber. Federico Paratore. Lucio Isa. ACS Nano. 2025.