# Reversible Chemotaxis of Janus Emulsion Droplets

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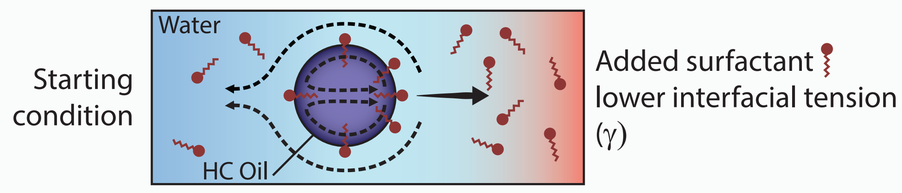
**Chemotaxis** is the ability of organisms to move in response to chemical stimuli, where environmental signals are transduced into recognition and motion.

**We explore** a model system where chemotactic motion and direction is controlled autonomously demonstrating that competing flows along fluid interfaces can define the speed and direction of biphasic droplets.

## Emulsion Droplet Chemotaxis via Marangoni Flows

Emulsion droplets chemotax in response to gradients of interfacial tension, induced by concentration of surfactant or changes in effectiveness.



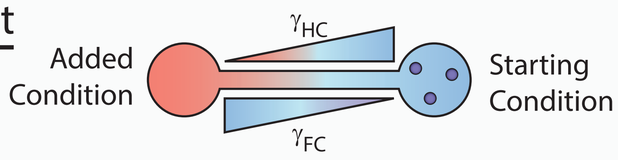

HC-water γ

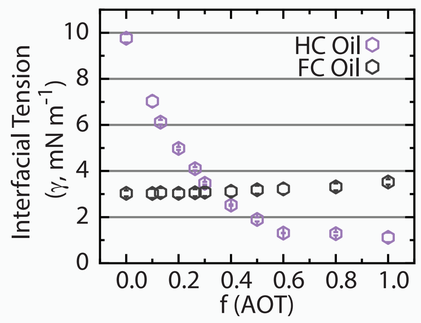
Marangoni flow induced force is proportional to droplet surface area and interfacial tension gradient

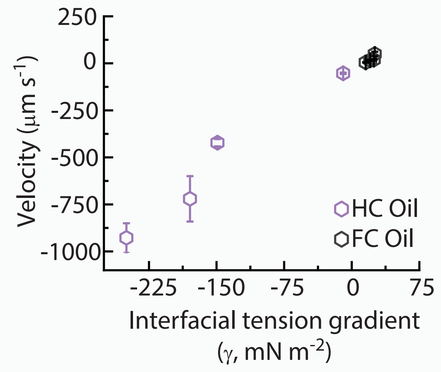
Movement is toward lower interfacial tension

## Droplets in a Surfactant Binary Gradient

For droplets in a binary (HC + FC) surfactant solution when pure surfactant solution (HC) is added to one end of a channel, two IFT gradients are generated.



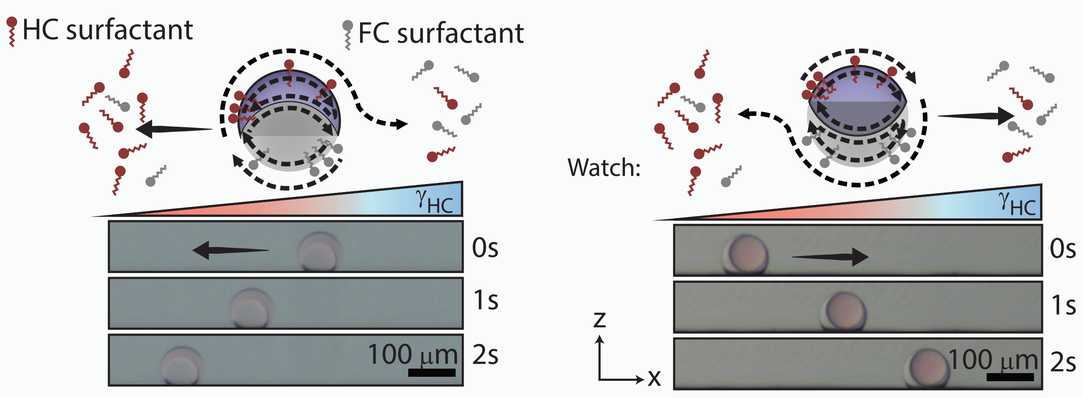

HC-water γ

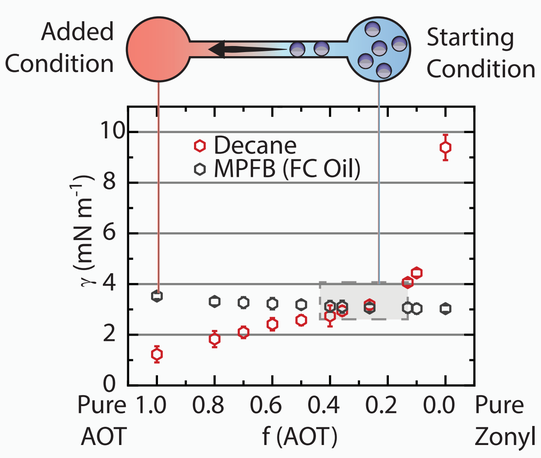
Movement is still toward lower interfacial tension, not added surfactant

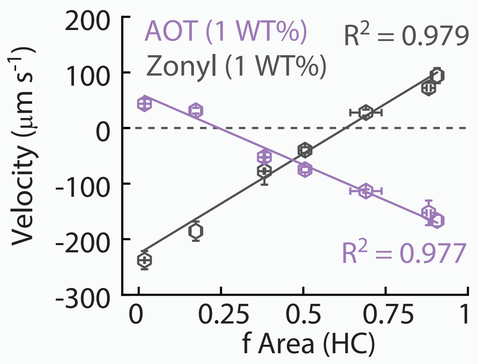
FC-water γ

## Chemotaxis Speed and Direction is Morphology-Determined

Under uniform conditions droplets chemotax in the +x or -x direction is dependant on the starting balance of exposed surface area



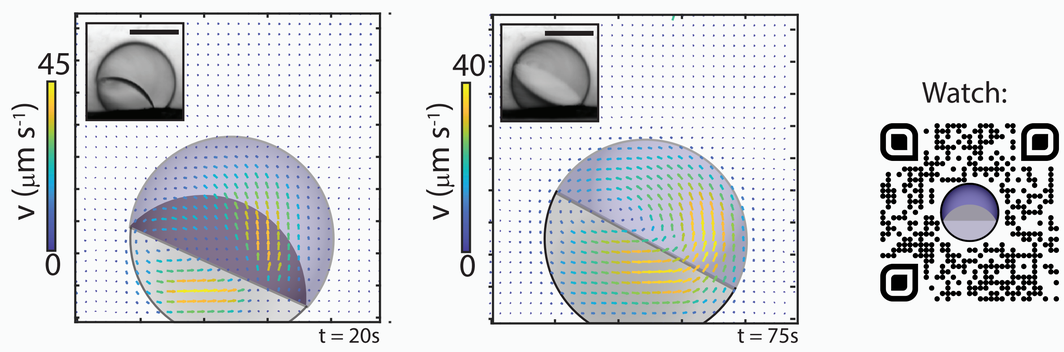




Velocity is linear (and reversible) dependant on morphology in uniform conditions

## Janus Droplets with Binary Gradient-Induced Competitive Flows

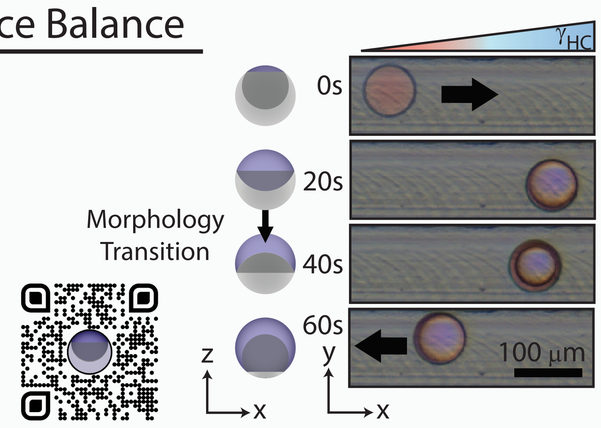
Janus droplets in a binary surfactant gradient have Marangoni convenctions at either interface, in the direction of the respective gradient, visualized by particle tracers (scale bar = 50 μm)




## Adaptivity from Changing Force Balance

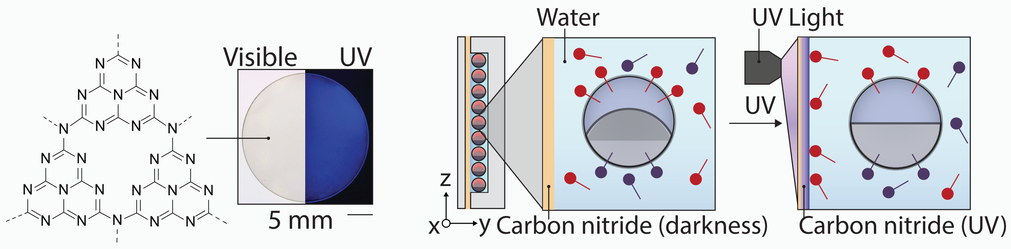
Droplet speed and direction is determined by morphology and $\nabla\gamma$

Droplet morphology reconfiguration can induce direction reversal: an autonomous decision made by purely chemical liquid objects



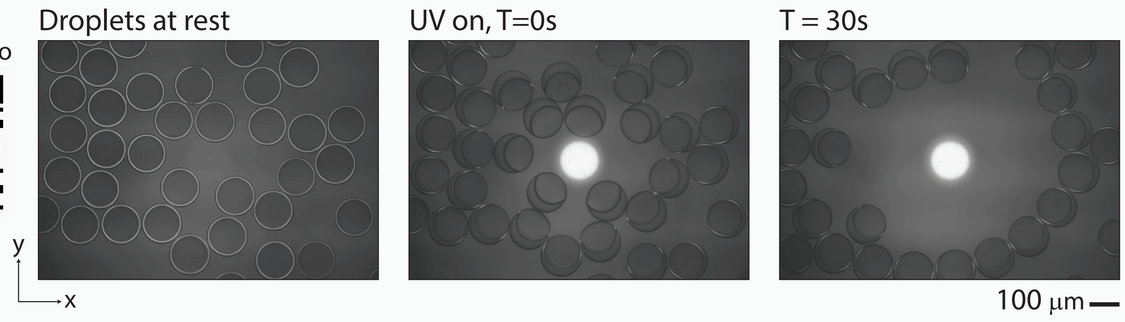

## Actuation & Motion in Photo-chemical gradients

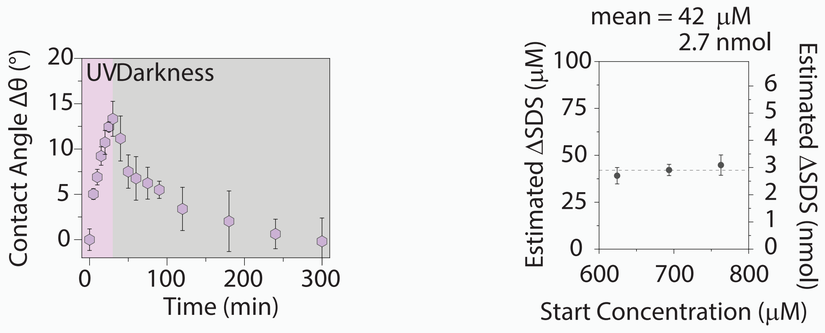
Carbon nitride, a polymeric semiconductor, generates charges under ultraviolet illumination. Using a counter-charged surfactant (SDS), reversible charging can induce varied concentrations of surfactant.




Droplets also respond to thermal- and photo-chemical gradients. These lessons can be applied to new photo-generated gradients to better understand their behavior *in situ*

Watch a video



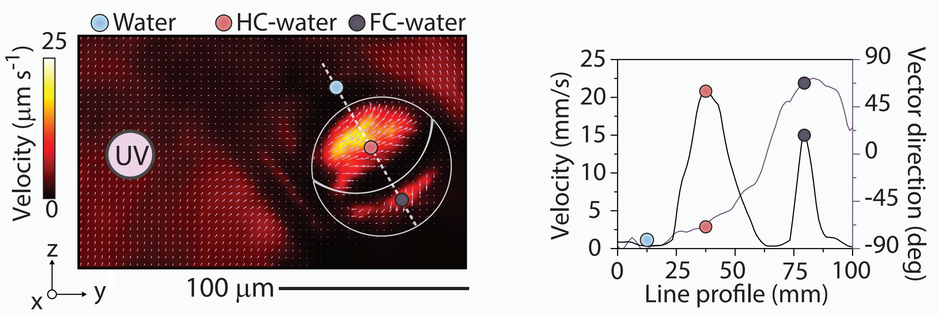







Fluid flows which induce droplet tilting out of alignment can be induced by photo-chemical and photo-thermal gradients, in morphology-dependent competition

Watch a video







Droplets reversibly change their morphology, which can be characteristically linked to measure the amount of adsorbed surfactant, closely matching expected surfactant adsorption ~10% error.

Bradley D. Frank, Saveh Djalali, Agata W. Baryzewska, Paolo Giusto, Peter H. Seeberger, Lukas Zeininger. *Nature Communications* 13, 2562 (2022)
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