Droplet Optics: From Responsive Emulsions to Pathogen Sensors

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MAX PLANCK INSTITUTE OF COLLOIDS AND INTERFACES

1. Pablo Simón-Marqués, Bradley D. Frank, Aleksandr Savateev, Lukas Zeininger, Adv. Opt. Mater 2021
2. Bradley D. Frank, Sara Nagelberg, Agata W. Baryzewska, Pablo Simón-Marqués, Markus Antonietti, Mathias Kolle, and Lukas Zeininger, (in revision)
3. Agata W. Baryzewska, Christian Roth, Peter H. Seeberger, and Lukas Zeininger, (in revision)

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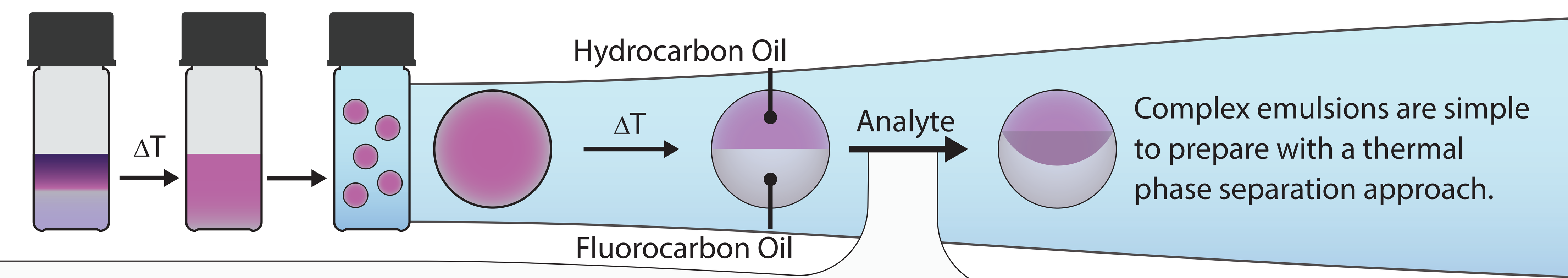
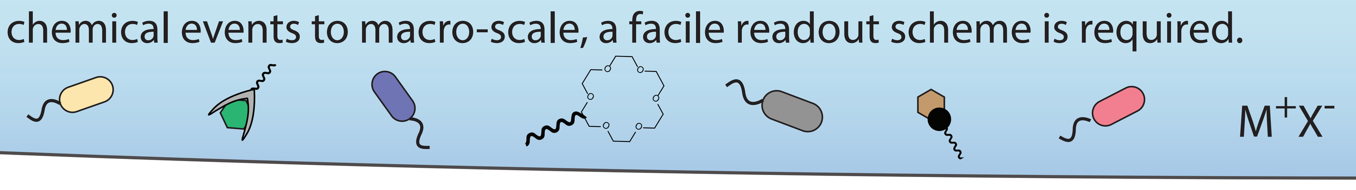
Sensors are stimuli responsive materials. Complex emulsion droplets respond to changes in chemical information as morphological transformation, characteristically.

We explore one pathway for multiplexed, reference-free, and ratiometric measurement of emulsion droplet programmable reconfiguration via concentrating and directing fluorescent light.[1,2]

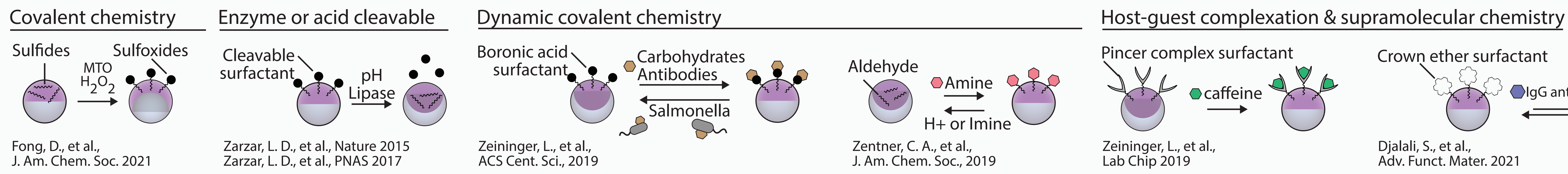


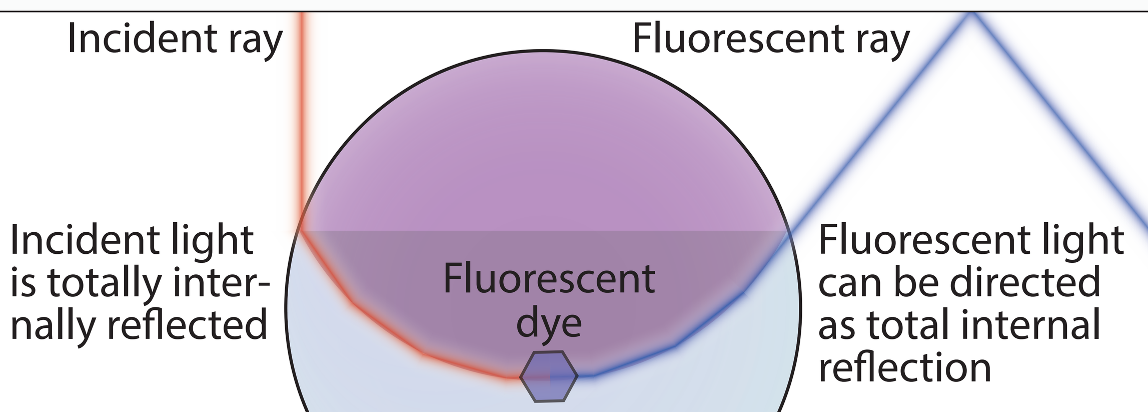
Interfacial programming via chemical orthogonality

The physical response of emulsion droplets is established for a variety of analytes. To establish the transduction of nano-scale chemical events to macro-scale, a facile readout scheme is required.



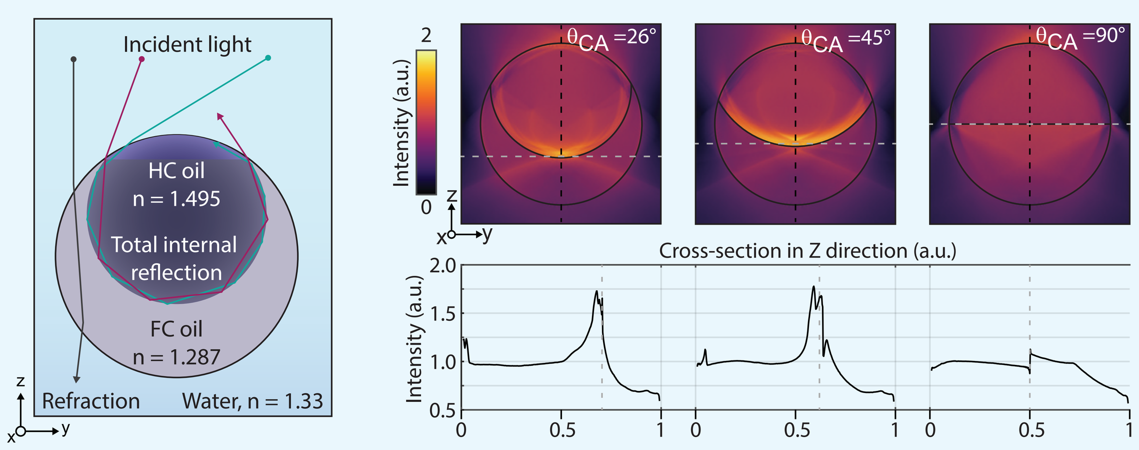
Some existing detection pathways[1]





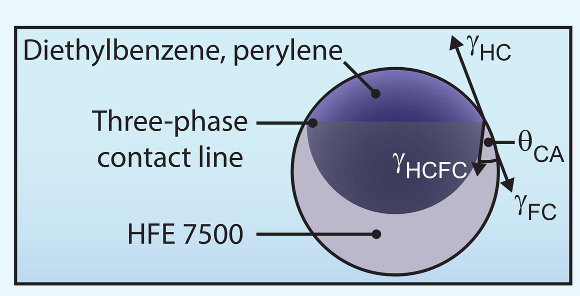
How can we translate nano-scale chemical events into a characteristic macro-scale signal?

Emulsion droplets collect incident light[1,2]

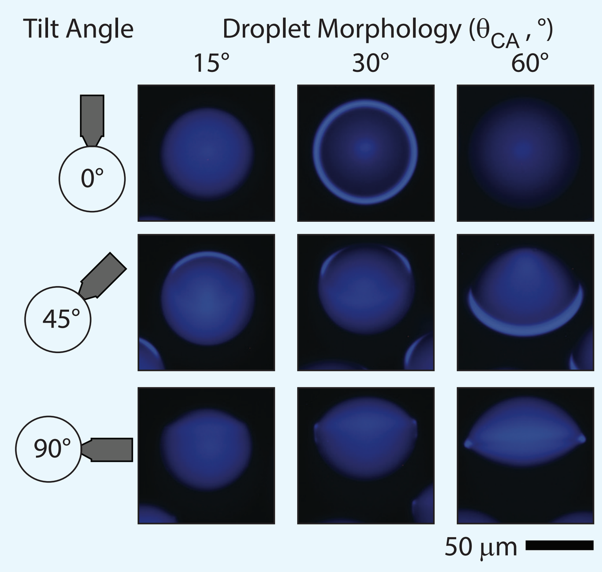


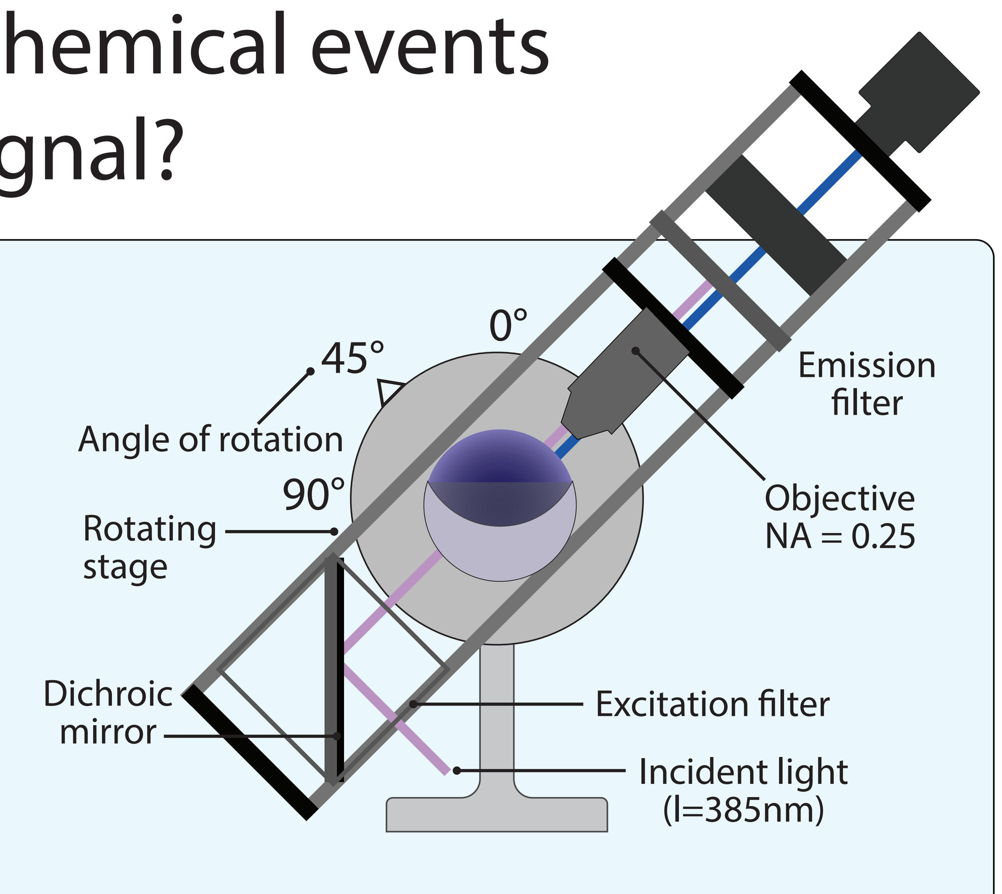
Light totally internally reflects along the internal hydrocarbon-fluorocarbon interface, dependant on refractive indices and droplet morphology.

Light is directed by the three-phase interface[2]



When a fluroescent dye is placed within the hydrocarbon phase, an annular fluorescent ring can be viewed only at particular angles.

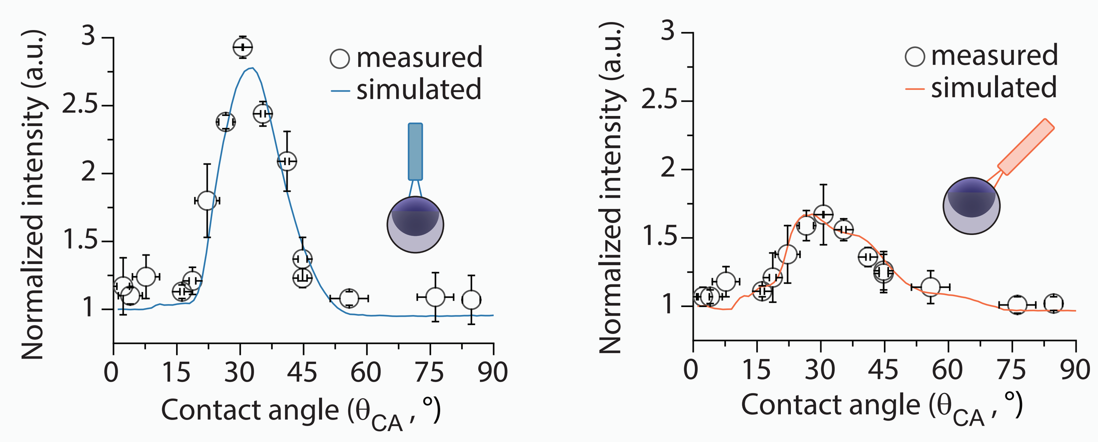




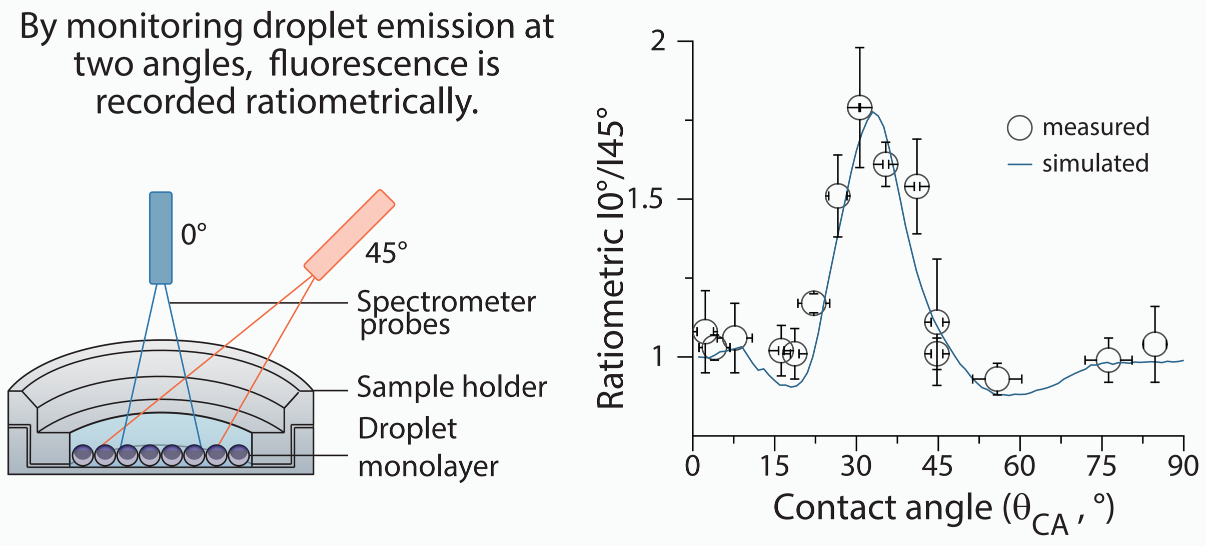
Complex droplets align with gravity, a rotating fluorescence microscope is used to image droplets at any angle.

Droplet monolayers as a reference-free sensor[2]

We monitor the fluorescence of layers of dyed Janus emulsion droplets.

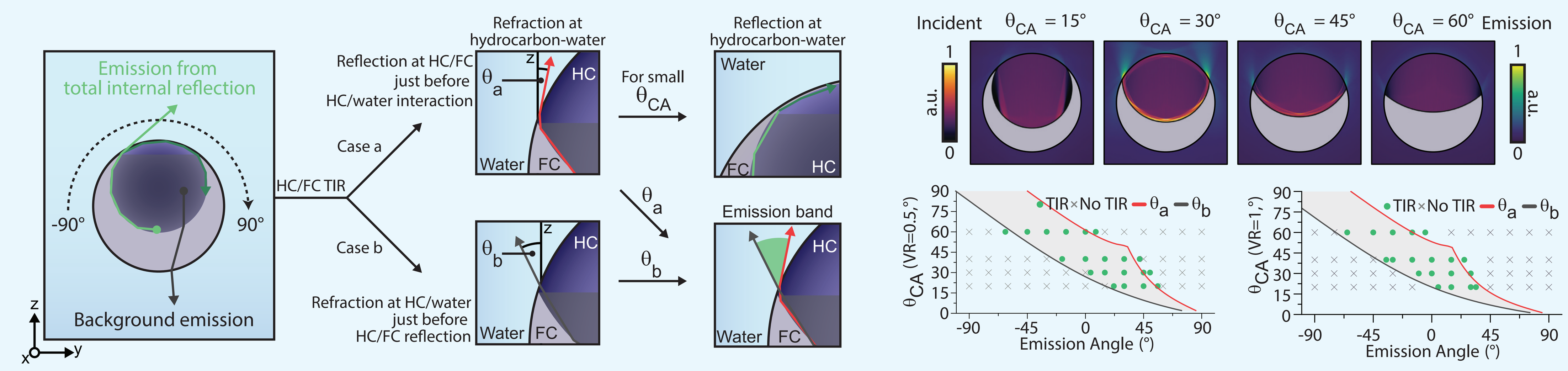


By monitoring droplet emission at two angles, fluorescence is recorded ratiometrically.

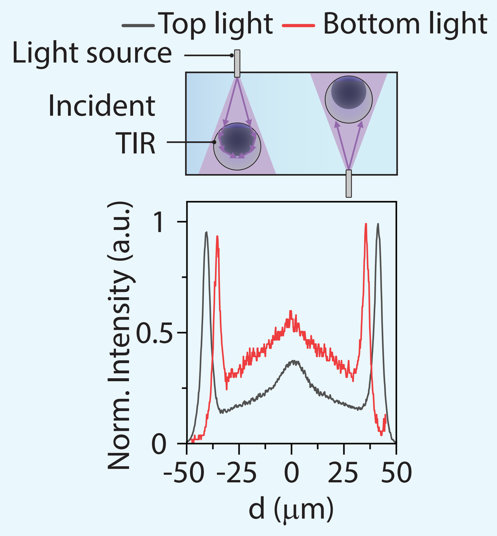


Ratiometric morphology determination is analyte-chemistry independent, and enables polydisperse emulsions for on-site application: translating nano-scale chemical events into macro-scale fluorescence signal.

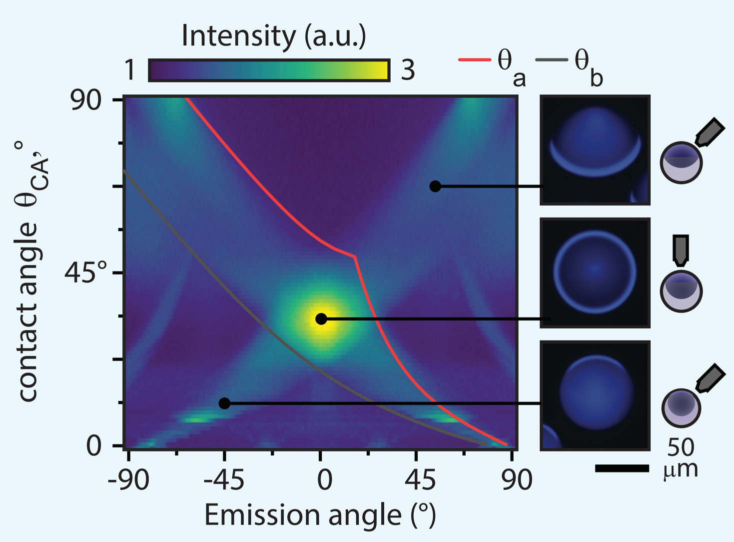
Totally internally reflected rays are interfacially-guided until possible exit[2]



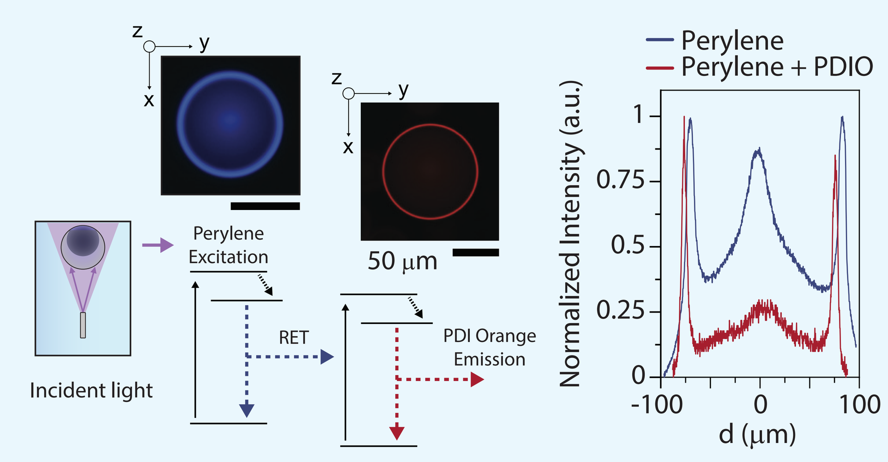
Angular emission can be calculated analytically, and is modelled via ray tracing, displaying a verifyable trend.



Total internal reflection of incident light enhances fluorescence

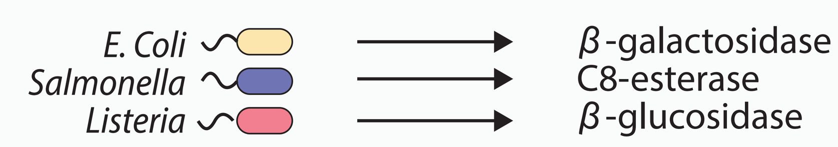


Geometrical and ray tracing modelling match experimental results

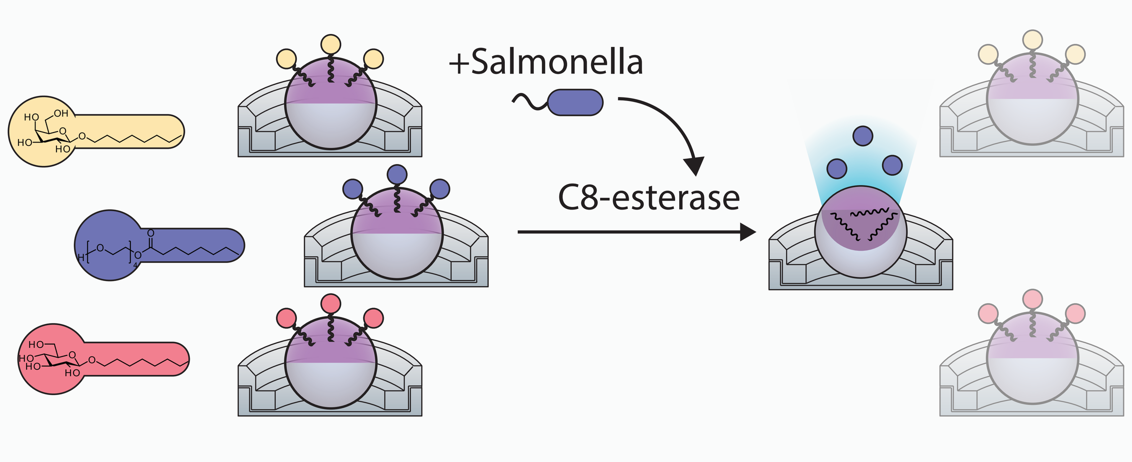


We can include a second dye in the hydrocarbon phase to collect the concentrated perylene emission, enhancing the signal-to-noise ratio of the emission

Droplets as foodborne pathogen sensors[3]



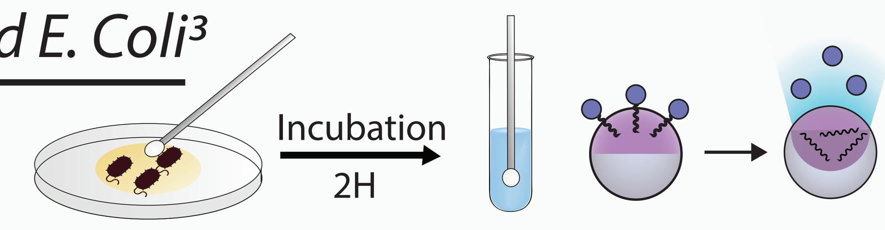
We target three major foodborne bacteria which release characteristic enzymes. Cleavable surfactants act as targeted enzymatic substrates.

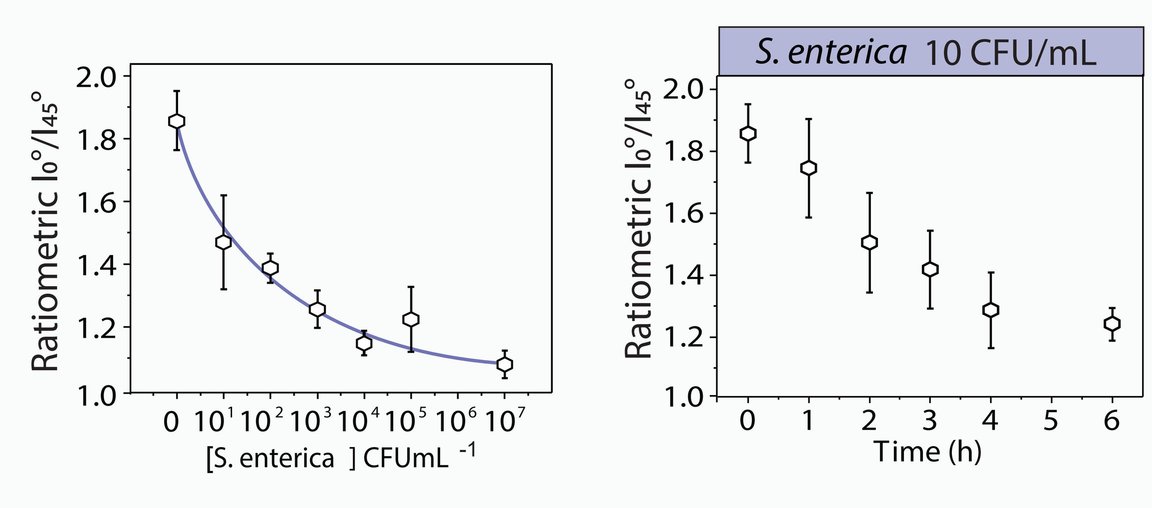


Ratiometric detection of droplet fluorescence serves as a chemistry-independent readout for polydisperse emulsion samples.

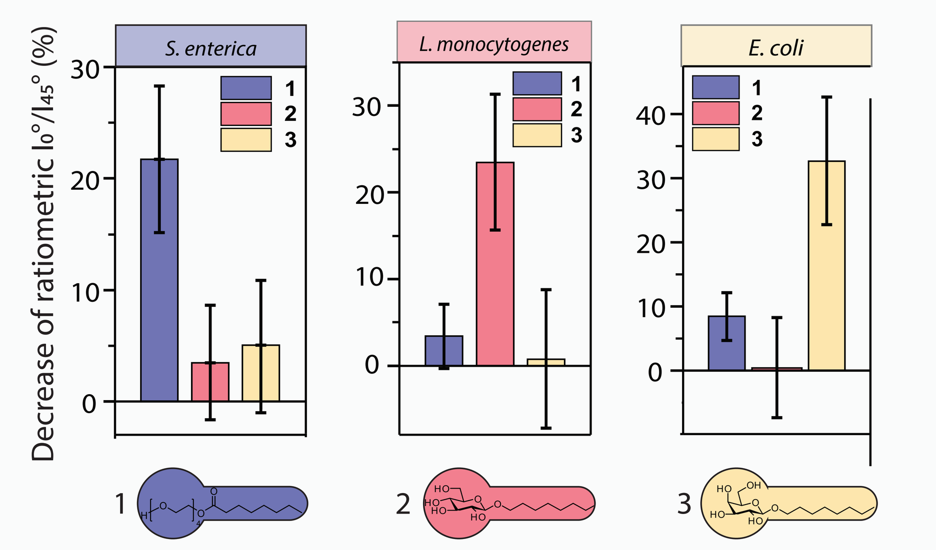
Ratiometric detection of *Salmonella, Listeria, and E. Coli*[3]

1. Bacteria are incubated in substrate solutions
2. After a period of time, droplets are prepared in the solution
3. Ratiometric fluorescence intensity is tested





C8-esterase released by Salmonella cleaves the substrate, demonstrating sensitivity to 10 bacterial cells per mL after 2 hours.



Cross tests and swab tests demonstrate high sensitivity and specificity toward targeted pathogens, and with ON-OFF behavior for deployment.

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