Active Volatile Drops on Liquid Baths

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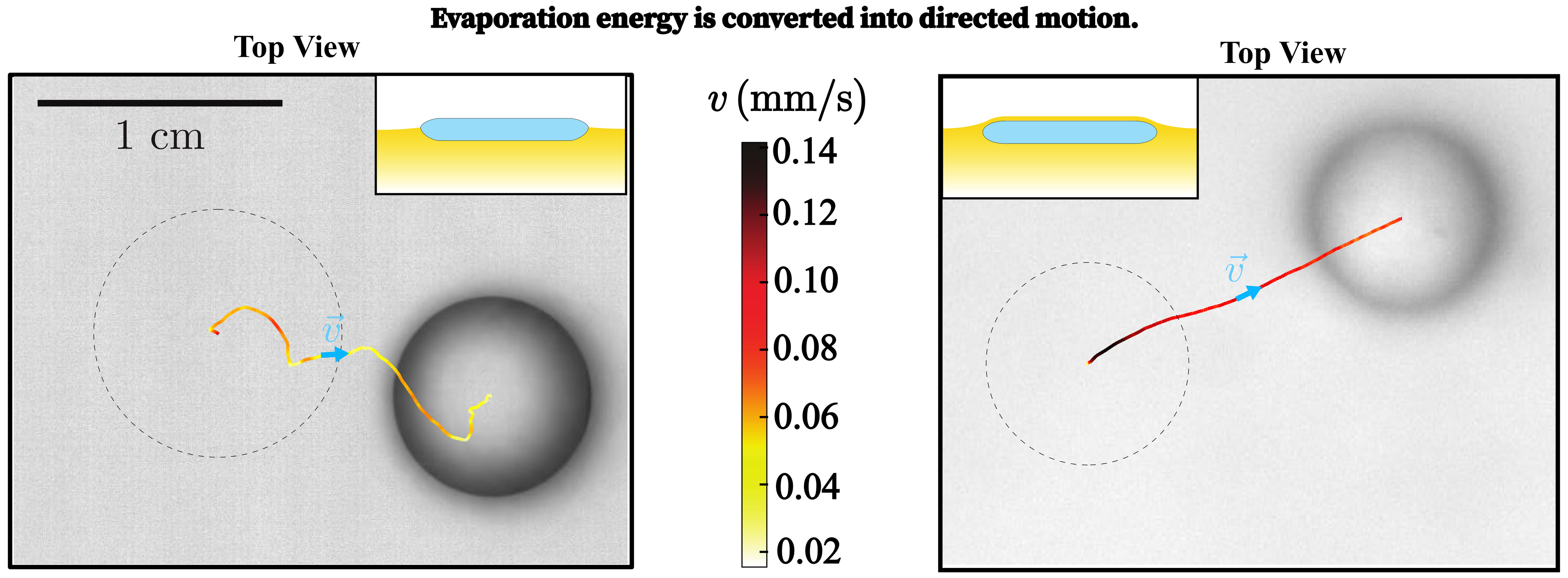
When a drop of volatile alcohol is deposited onto the surface of a bath of immiscible liquid, the drop spontaneously propels on the surface.

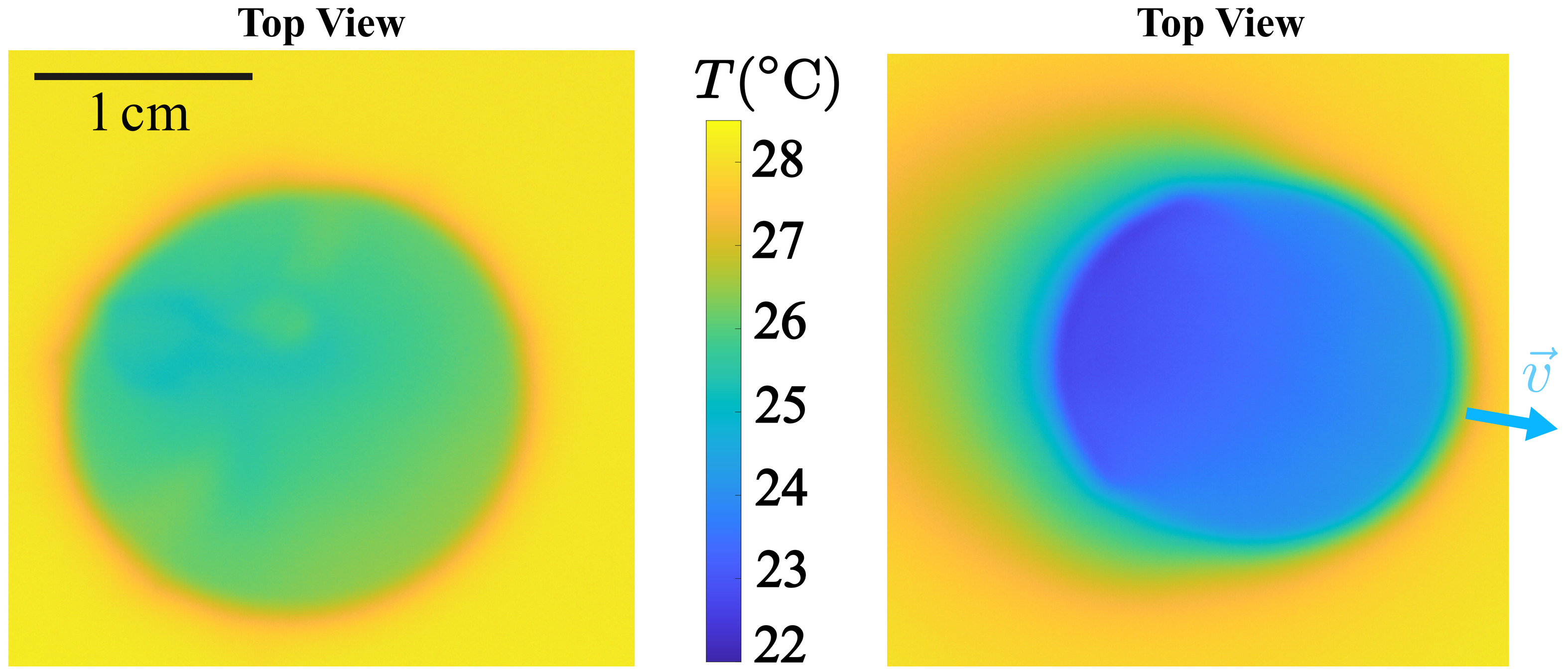
Evaporation energy is converted into directed motion.



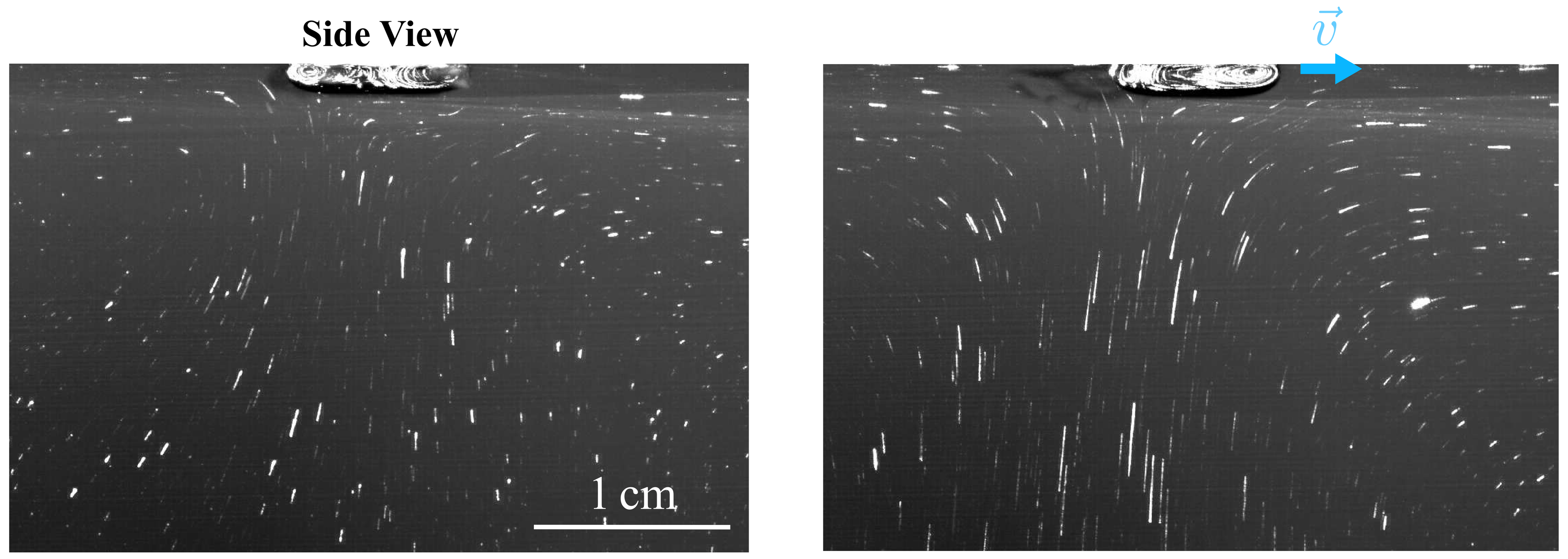
The presence of a thin film of bath liquid coating the drop is associated to straighter trajectories.

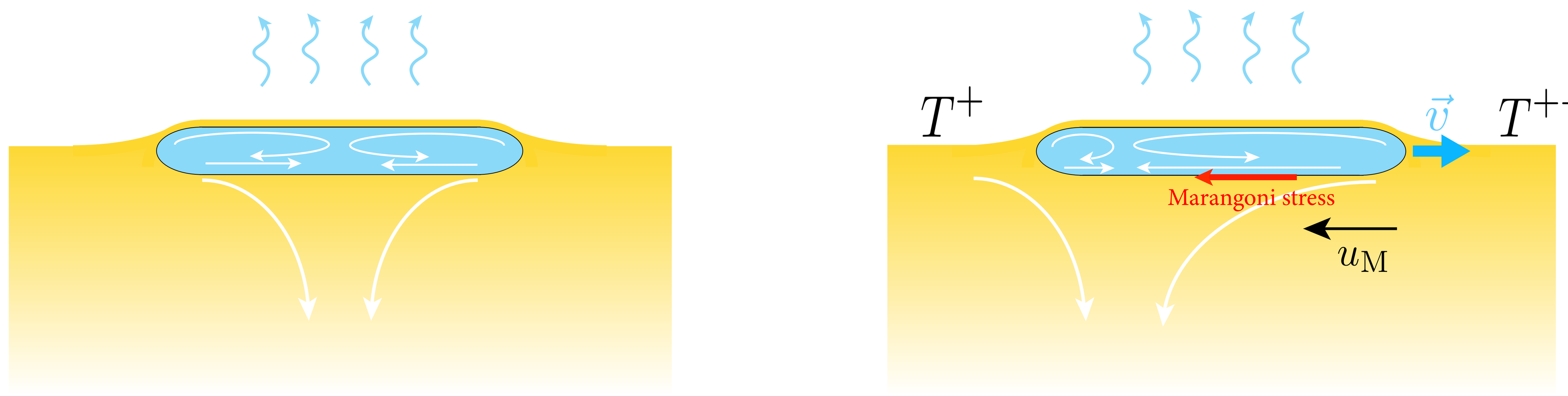
Self-propulsion is triggered by a thermocapillary convective instability.

Spontaneous symmetry breaking of the surface temperature field...



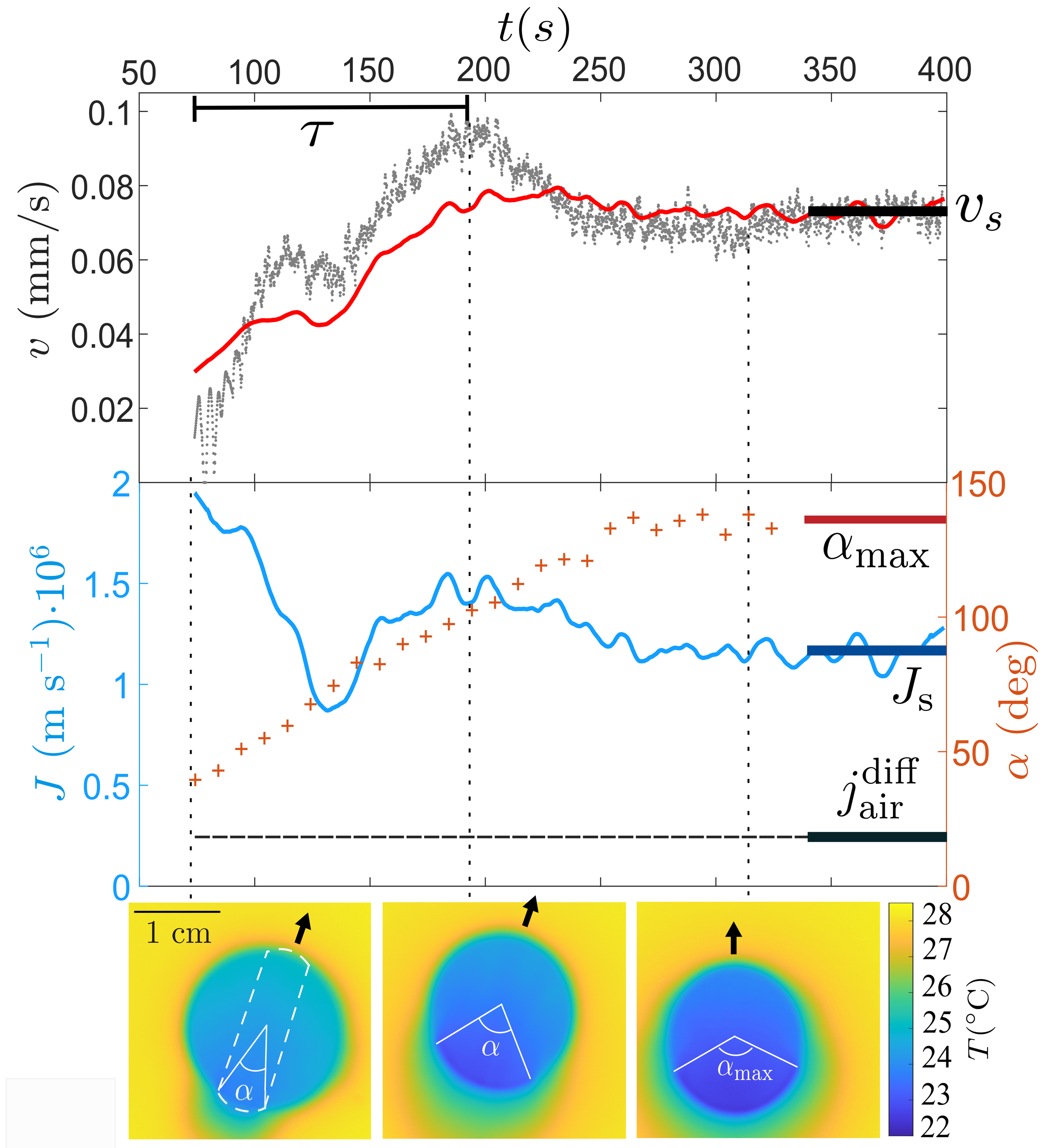
...results into asymmetric thermocapillary stresses and symmetry breaking of the hydrodynamic flows.





A propulsive force emerges as a result of the viscous stress response of the liquid bath to the Marangoni stress exerted on the drop's lower interface.

Relation between the drop velocity and the evaporation flux J (i.e. the activity source) in the transient regime?



Force balance between Marangoni traction and Stokes drag

$$v \sim \left|\frac{d\gamma}{dT}\right| \frac{\Delta T}{\eta_2} \quad \text{with} \quad \Delta T = T^{++} - T^{+}$$

Interfacial tension γ

Bath viscosity η_2

Thermal balance dominated by heat convection

$$\rho_2\, C_p\, \Delta T u_M \propto \rho_1 \mathcal{L}_v J$$

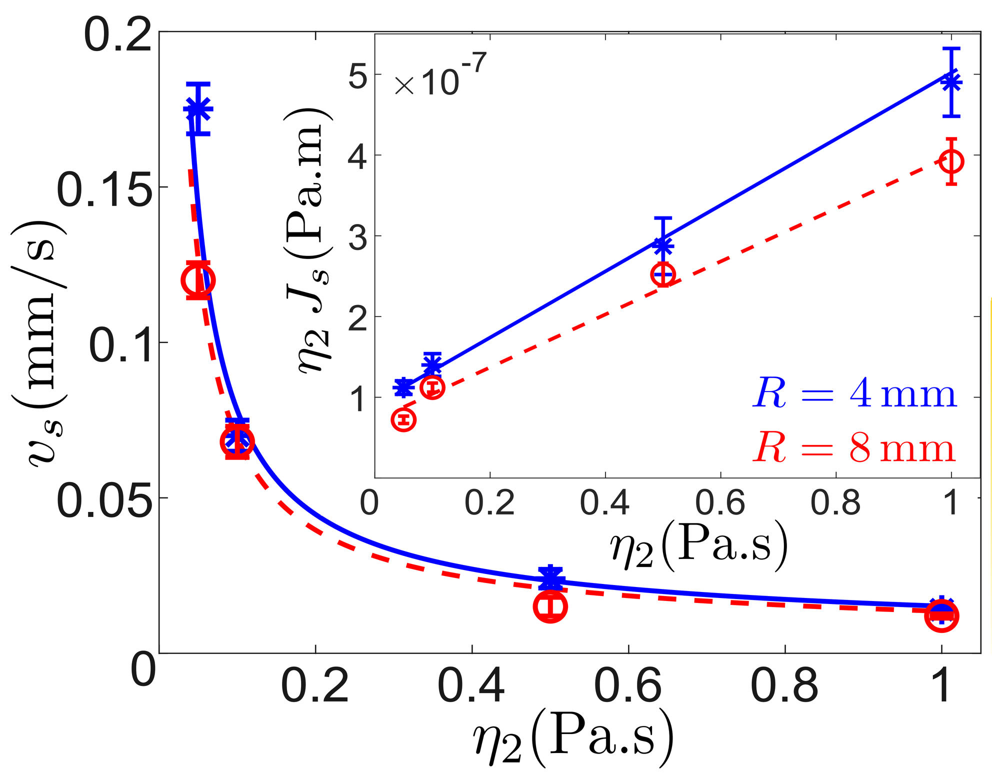
with the velocity of the Marangoni flow

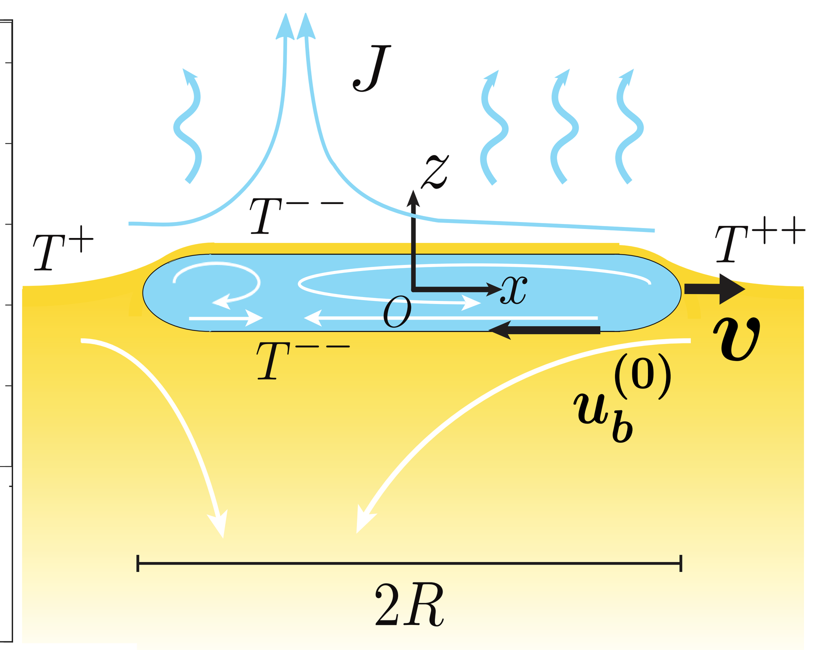
$$u_M \sim \left|\frac{d\gamma}{dT}\right| \frac{\Delta T}{\eta_2}$$

Combining force and thermal balance

$$v \sim \left[\frac{\rho_1 |d\gamma/dT| \mathcal{L}_v J}{\rho_2\, \eta_2 C_p}\right]^{1/2}$$

In the stationnary regime, the activity of the system can be tuned by varying bath viscosity η_2





Evaporation is governed by two transport processes of vapour in air, diffusion and convection.

The evaporation flux is the sum of a diffusion and a convection contribution

$$J_s = a + b/\eta_2$$

Drop velocity at variable activity is well captured for different radii by combining force and thermal balances

$$v_s \sim \left[\frac{\rho_1 |d\gamma/dT| \mathcal{L}_v (a + b/\eta_2)}{\rho_2\, \eta_2\, C_p}\right]^{1/2}$$

In contrast to a solid Marangoni surfer, our drop propels in a direction opposite to the interfacial tension gradient.
The propulsion scheme is rather similar to a classical squirmer developping tangential stress on its interface to sustain its locomotion.

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