Flower - like azimuthal instability of axisymmetrically - fed surface flows

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We are interested in the propulsion mechanism of micrometer - sized swimmers within self - induced Marangoni flows in the low Reynolds number regime. The flows of interest are due to temperature or concentration inhomogeneities. The project is based on the observation that *initially axisymmetric flows on a water - air interface are azimuthally unstable.* In this presentation, this fact is illustrated by two experiments.

- Our first experiment (I) involves a micrometric carbon bead which is trapped at the water/air interface and heated up with a laser beam [1]. This hot spherical particle generates a temperature gradient that drives a thermocapillary flow. Most strikingly, the flow exhibits structures that range from slightly polar, to dipolar and even multipolar at sufficiently high laser powers.
- In our second experiment (II) we simply inject water through a narrow vertical tube located below the WA interface. The gap between the injector and the interface ($\sim$ 1mm) is kept constant by means of a feedback loop. The fluid contains a small amount of sodium dodecyl sulfate (SDS, cmc/100), a well - known surfactant. Gradients in the surface concentration of SDS play a role analogous to that of temperature gradients in (I) as being the source of Marangoni flows. Similarly to what occurs in (I) we observe a symmetry - breaking of the primary axisymmetric flow in the form of complex dipolar and even multipolar patterns.

Dipolar flows (Fig.1 below), emerging as pairs of contra - rotating vortices, are thought to be the mechanism by which hot spherical particles move at large velocities ($\sim$ 100 particle diameter/s) on the WA interface. Such flows stem from the destabilization of initially toroidal flows [2] that display similar shapes in both experiments (I) and (II). We currently focus our efforts on understanding how the instability sets in.

[1] A. Girot, N. Danné, A. Würger, T. Bickel, F. Ren, J - C. Loudet, and B. Pouligny. 'Motion of Optically Heated Spheres at the Water – Air Interface.' *Langmuir* **32**, 2687-2697 (2016) .
[2] V. Shtern and F. Hussain. 'Azimuthal instability of divergent flows.' *J. Fluid Mech.* **252**, 518 (1993) .

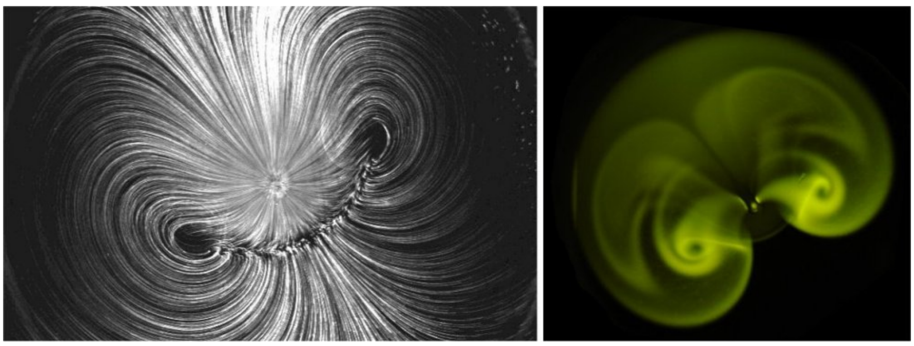

Figure 1: Example of a dipolar flow seen from above the WA interface in experiment (II). (a) : Streamlines (left). (b) : Structure unveiled by a droplet of fluorescent dye sent through the injector (right).