JMC 17 — Journées de la Matière Condensée — du 24 au 27 Août 2021

Minicolloque n° MMM13

Shrinking Surface Bubbles

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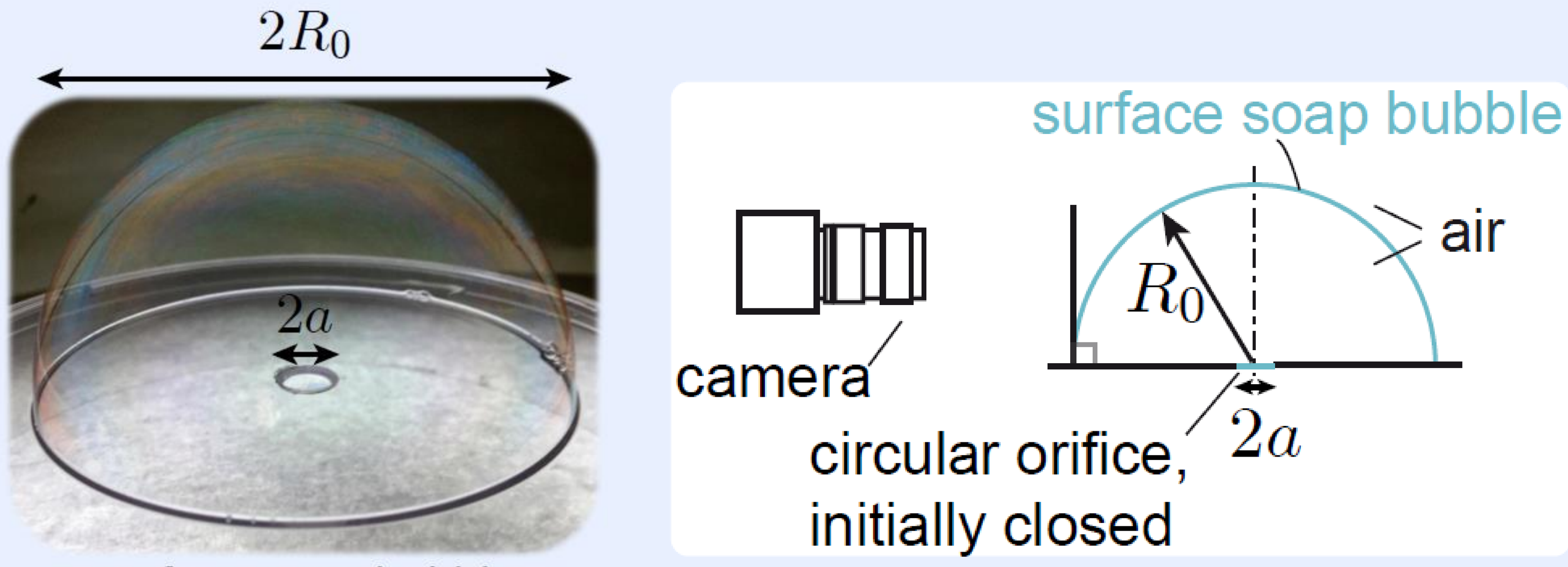
The draining of a tank is a problem that has been widely studied, beginning some 400 hundred years ago with the pioneering work of Evangelista Torricelli. Here, we discuss a variant of this problem by working with deformable tanks – soap bubbles sitting on thin solid plates with a circular orifice located under their apex. We observe three different shrinking behaviors which are modeled using simple physical arguments.

The setup

We prepare surface soap bubbles with an initial radius R_0 on thin plate. The apex of the bubble is located over a circular orifice of radius a initially closed.

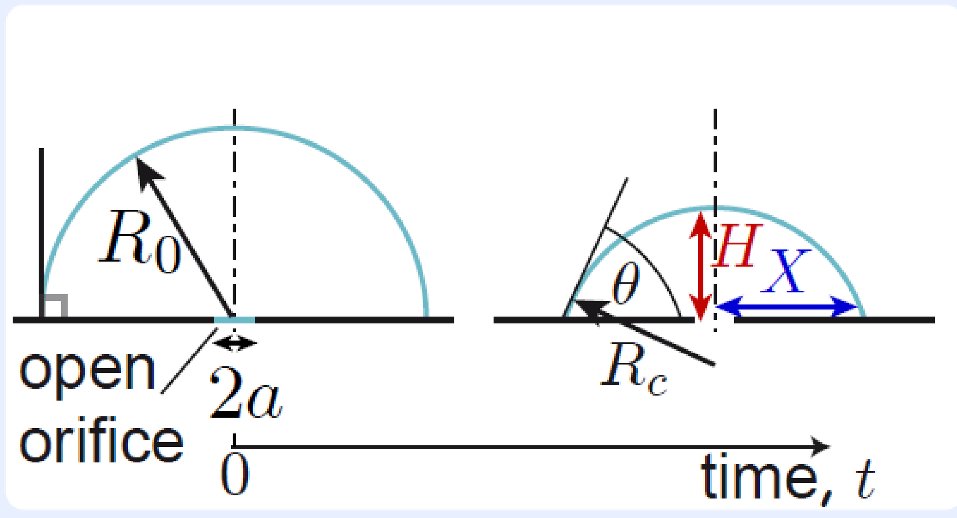


surface soap bubble

The experiment

Shrinking begins when the orifice is opened and we record the evolution with time t of three distances:

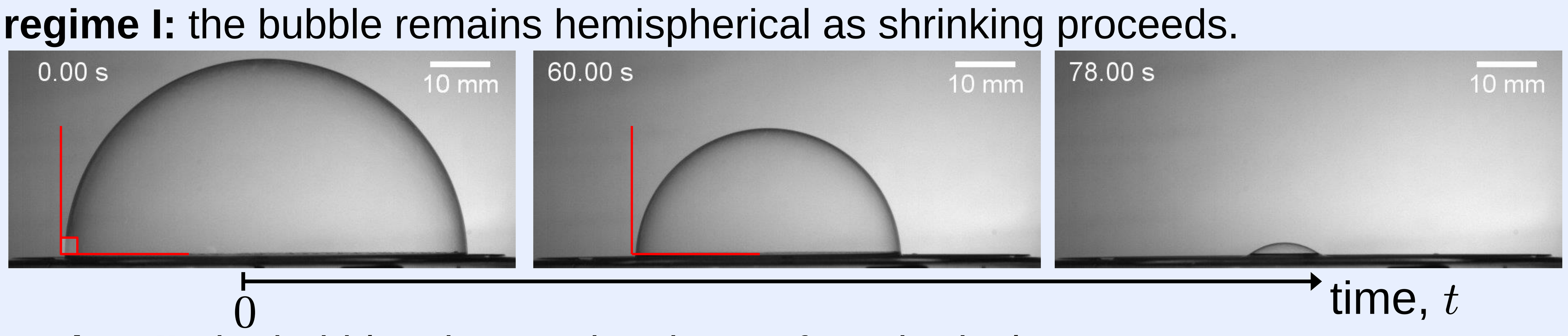
- the bubble's radius of curvature $R_c(t)$;
- the height $H(t)$ of the bubble at its center;
- the distance $X(t)$ between base of the bubble and orifice.



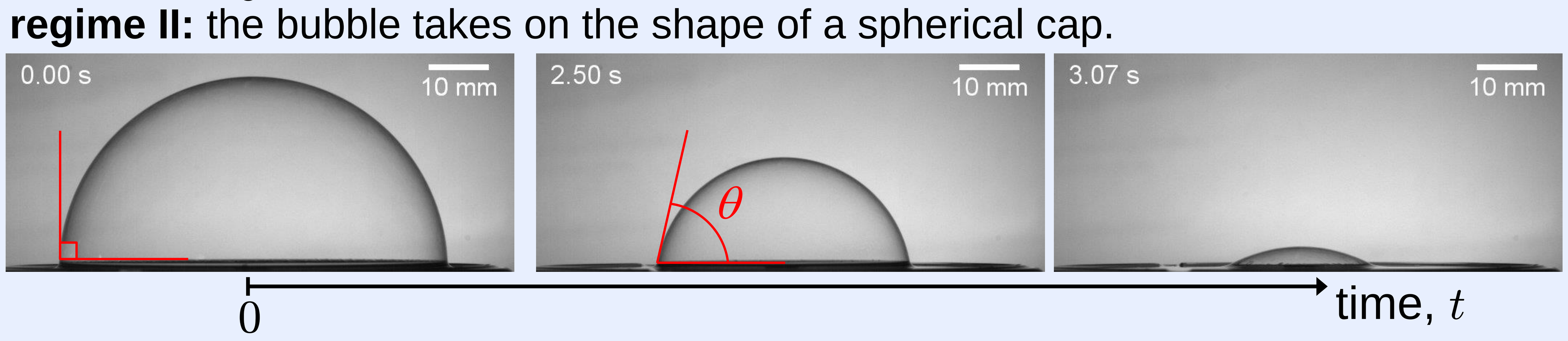
Three experimental shrinking regimes

Three regimes are seen experimentally. Their occurrence depends on key parameters of the problem: the size of the orifice and that of the initial bubble and physico-chemical properties of the fluid system.

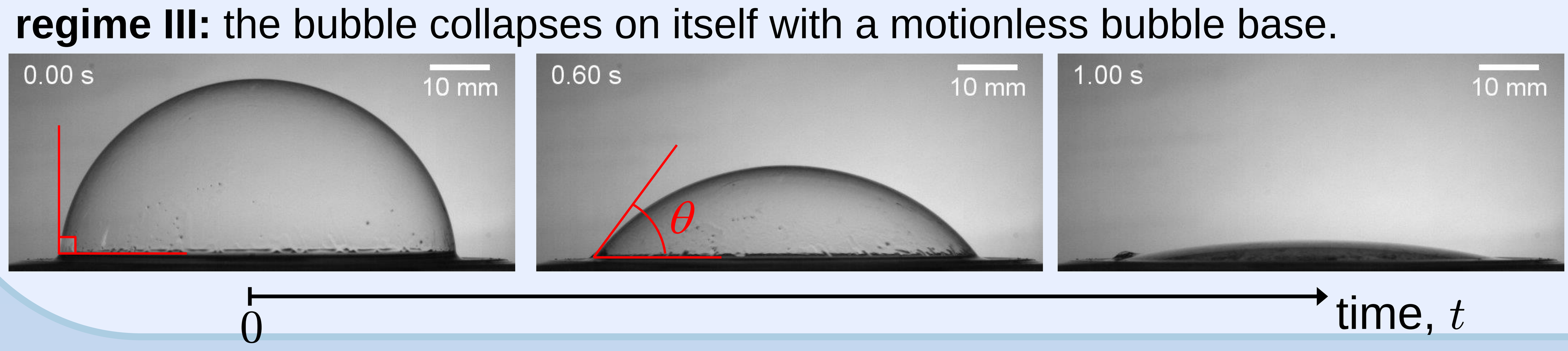
regime I: the bubble remains hemispherical as shrinking proceeds.



regime II: the bubble takes on the shape of a spherical cap.



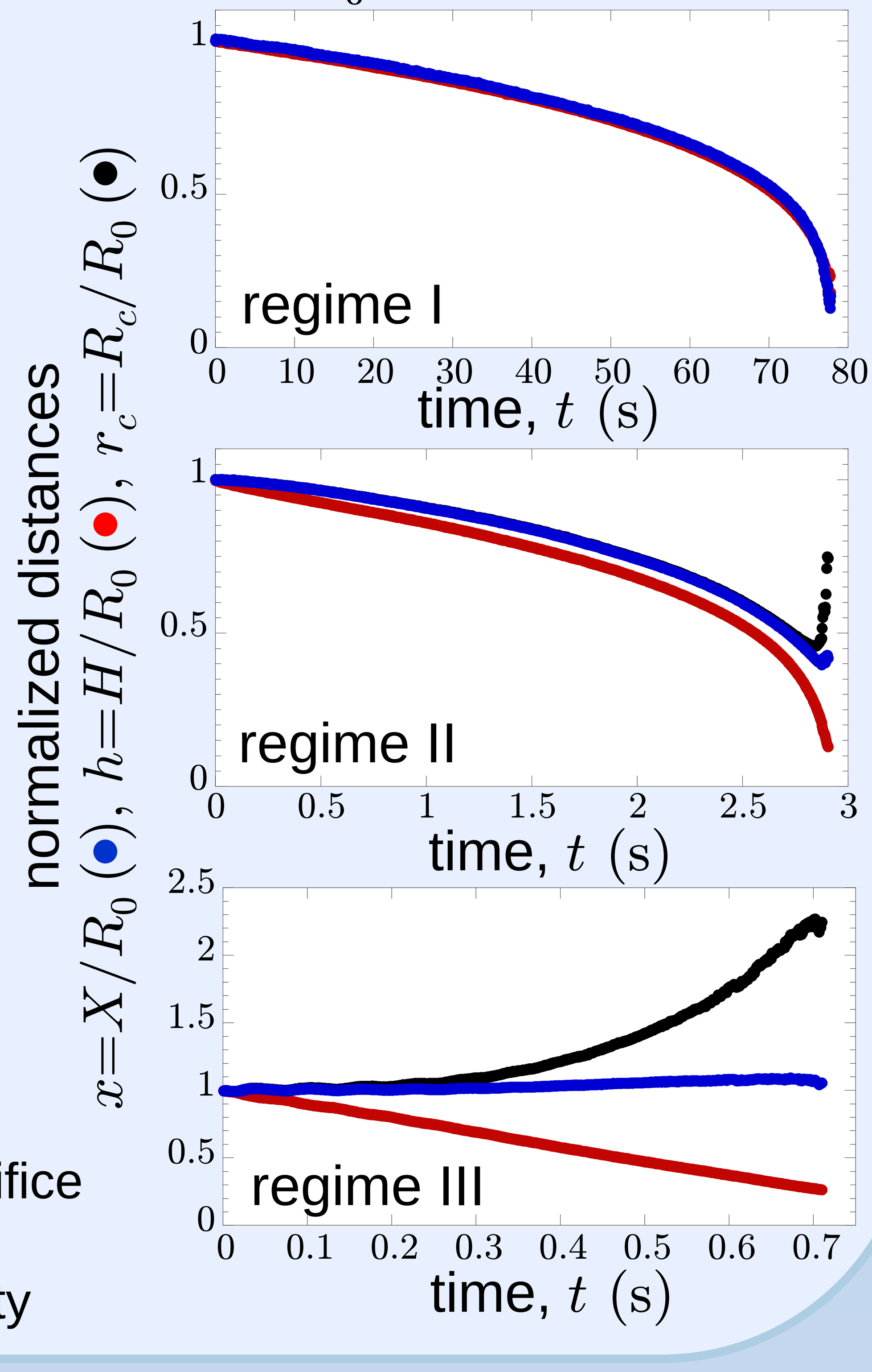
regime III: the bubble collapses on itself with a motionless bubble base.



radius of the orifice and/or liquid viscosity

constant initial radius

$R_0 = 33 \pm 1$ mm

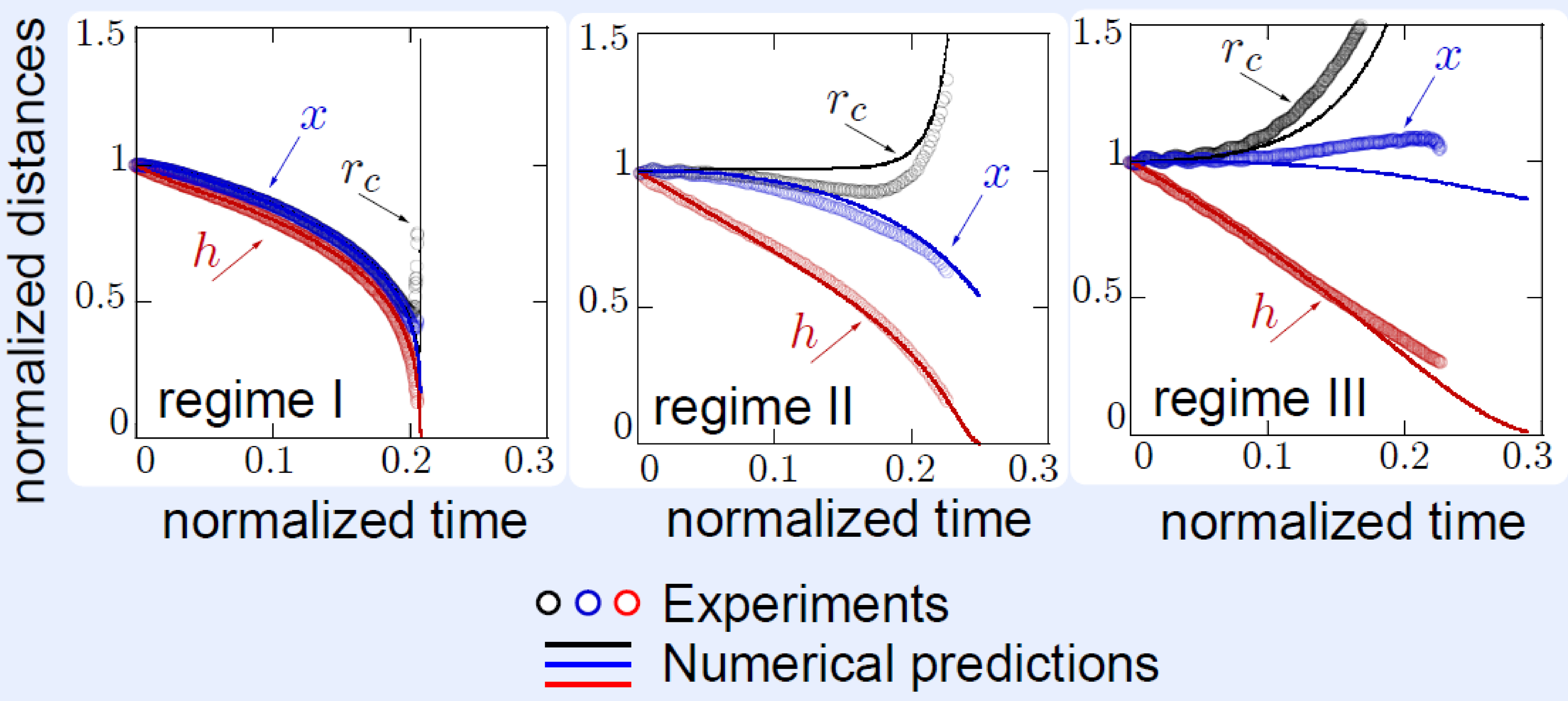


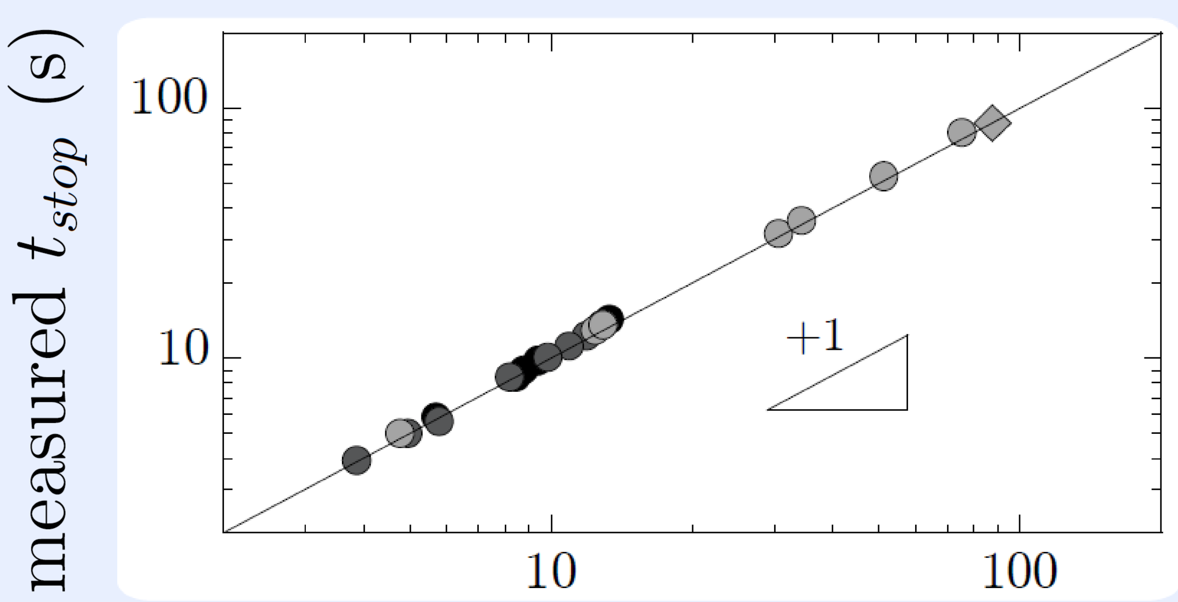
Modeling the flow

A simple model allows us to account for the shrinking regimes seen experimentally. The dynamics in all three regimes are modeled using

- Bernoulli's principle for the air flow;
- conservation of air flow rate;
- friction acting on the base of a bubble.

We obtain a set of differential equations for the normalized distances $r_c = R_c/R_0$, $h = H/R_0$ and $x = X/R_0$ that we solve numerically.





$$\text{predicted } t_{stop} = \frac{\sqrt{2}}{7}\left(\frac{R_0}{a}\right)^2 \sqrt{\frac{\rho_a R_0^3}{\gamma}} \text{ (s)}$$

In regime I, we derive an analytical solution for the time t_{stop} it takes the air to completely escape from the bubble. This predicted time compares well to experiments; ρ_a is the air density and γ is the air-liquid surface tension.

M. Clerget et al. Am. J. Phys. 89, 244 (2021)