Physics of Beer Tapping

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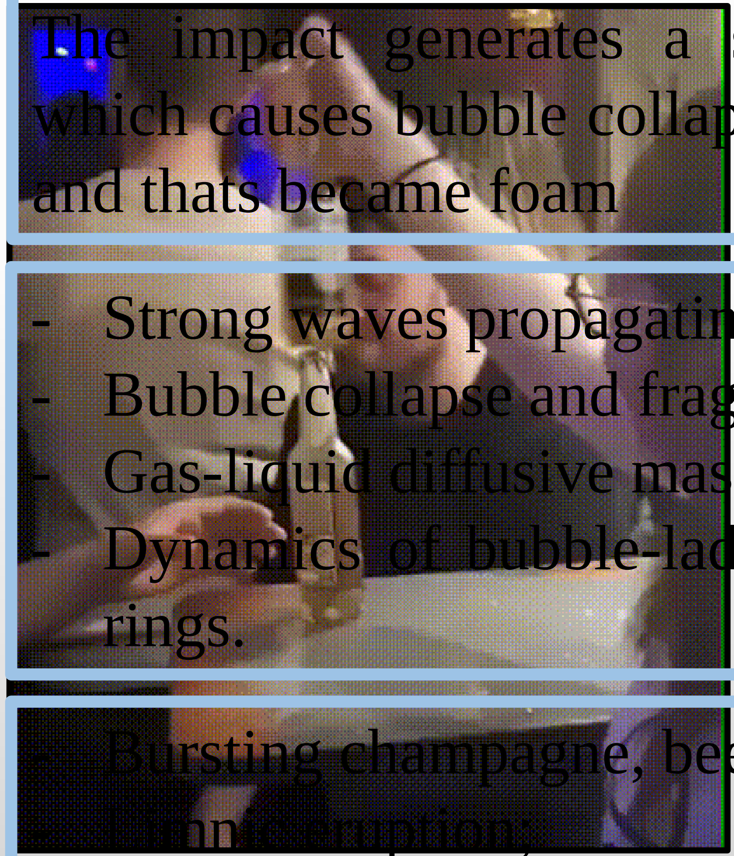
Introduction

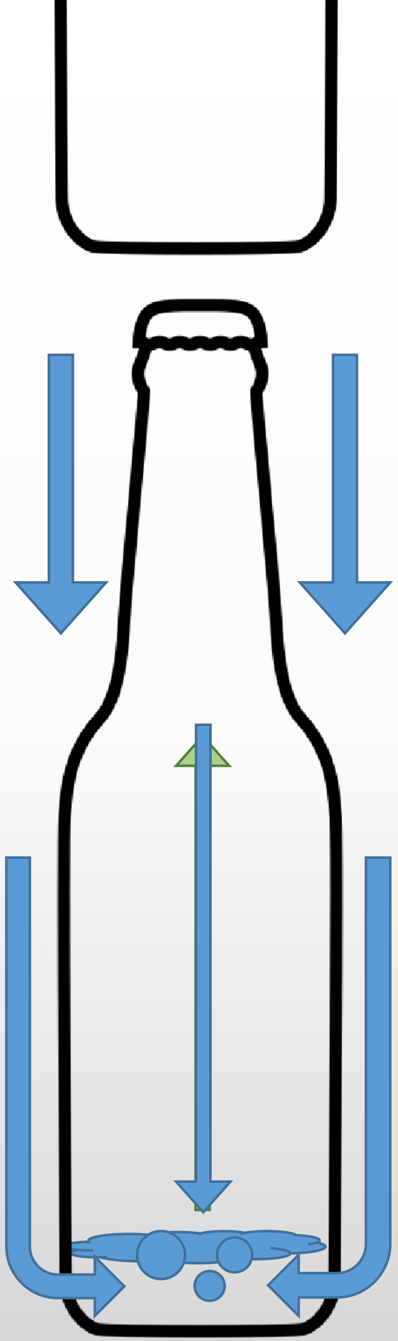
What is Beer Tapping?



The impact generates a strong wave pressure which causes bubble collapse and frangmentation and thats became foam

- Strong waves propagating on bubbly liquids;
- Bubble collapse and fragmentation;
- Gas-liquid diffusive mass transfer;
- Dynamics of bubble-laden plumes and vortex rings.

- Bursting champagne, beer tapping, etc;
- Limnic eruption;
- explosive eruption;



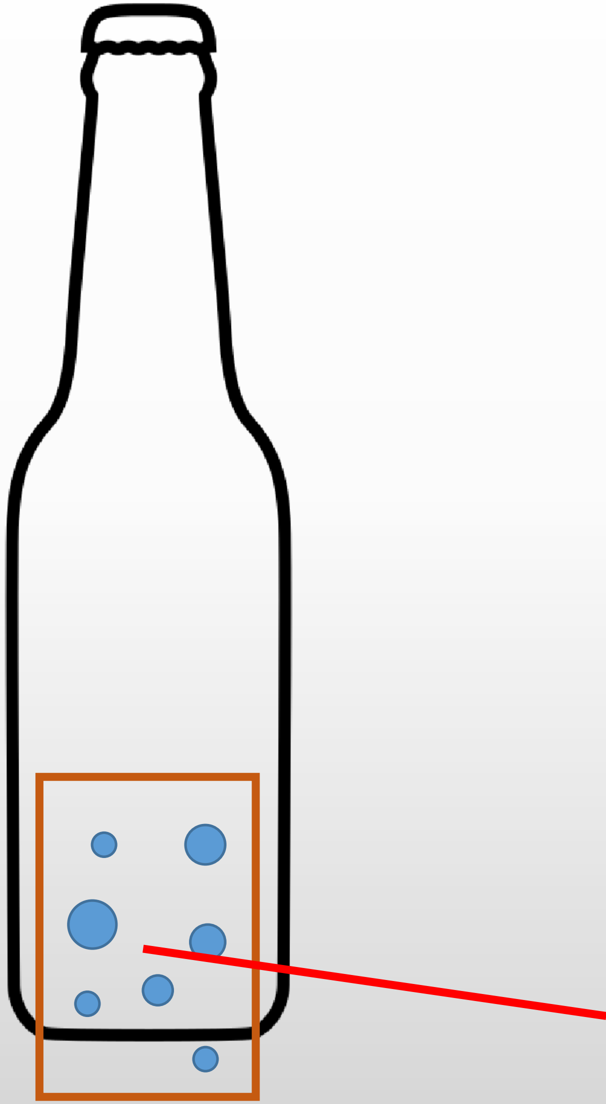
Methods

- Impacting commercial beer bottles under repeatable contidions;

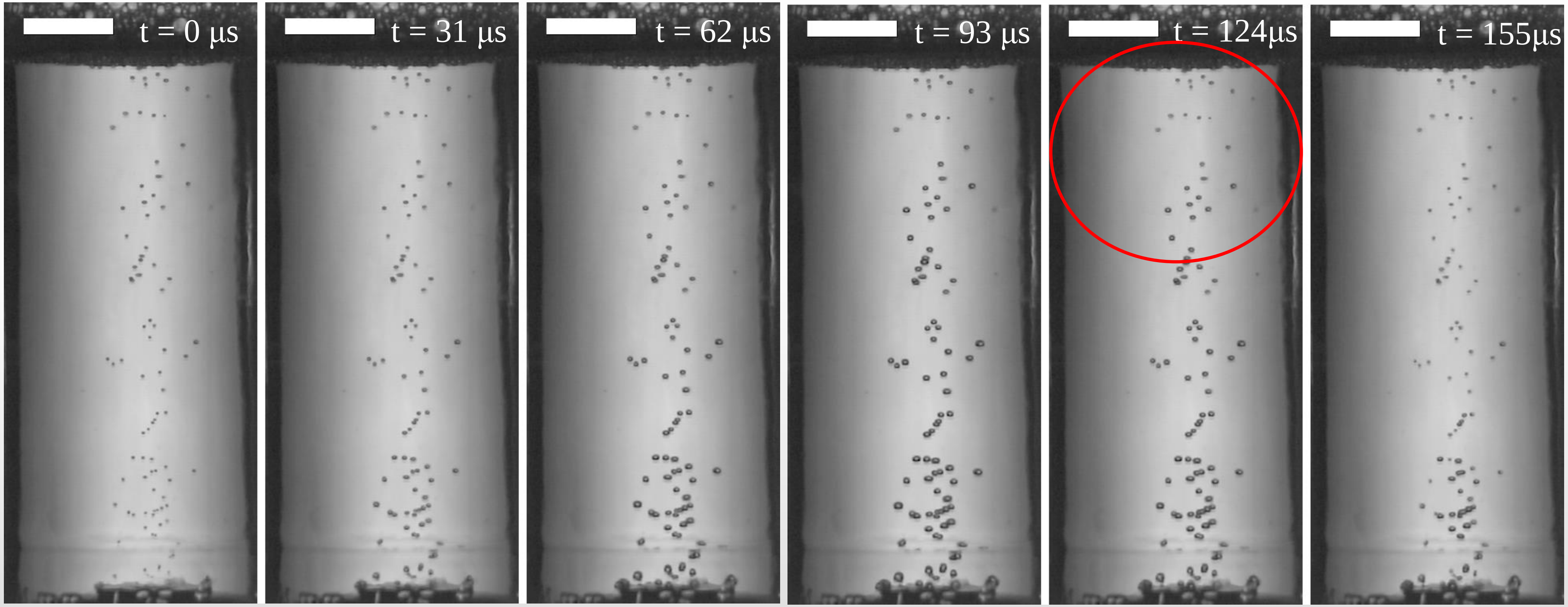
- Bubbles was generated in a fixed location far from the walls by focusing a laser pulse in bulk;
  - Avoid variability in the bubble formation;
  - The initial bubble size is known and always present in the measurement volume;

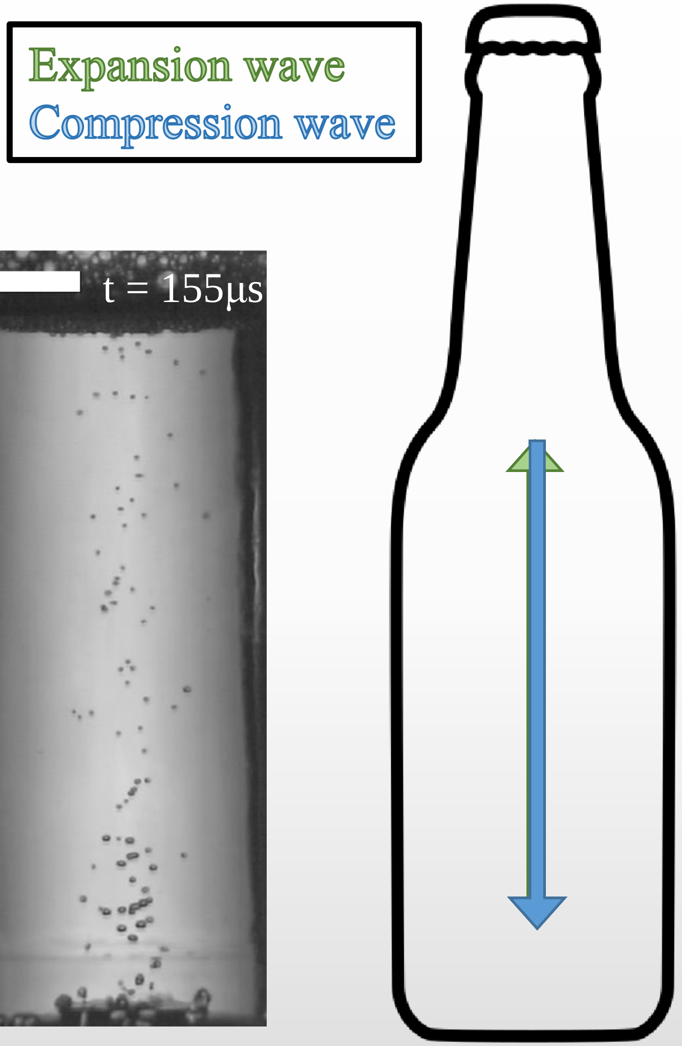
- The evolution was recorded with a high-speed camera;

- The liquid pressure temporal evolution with a hydrophone.



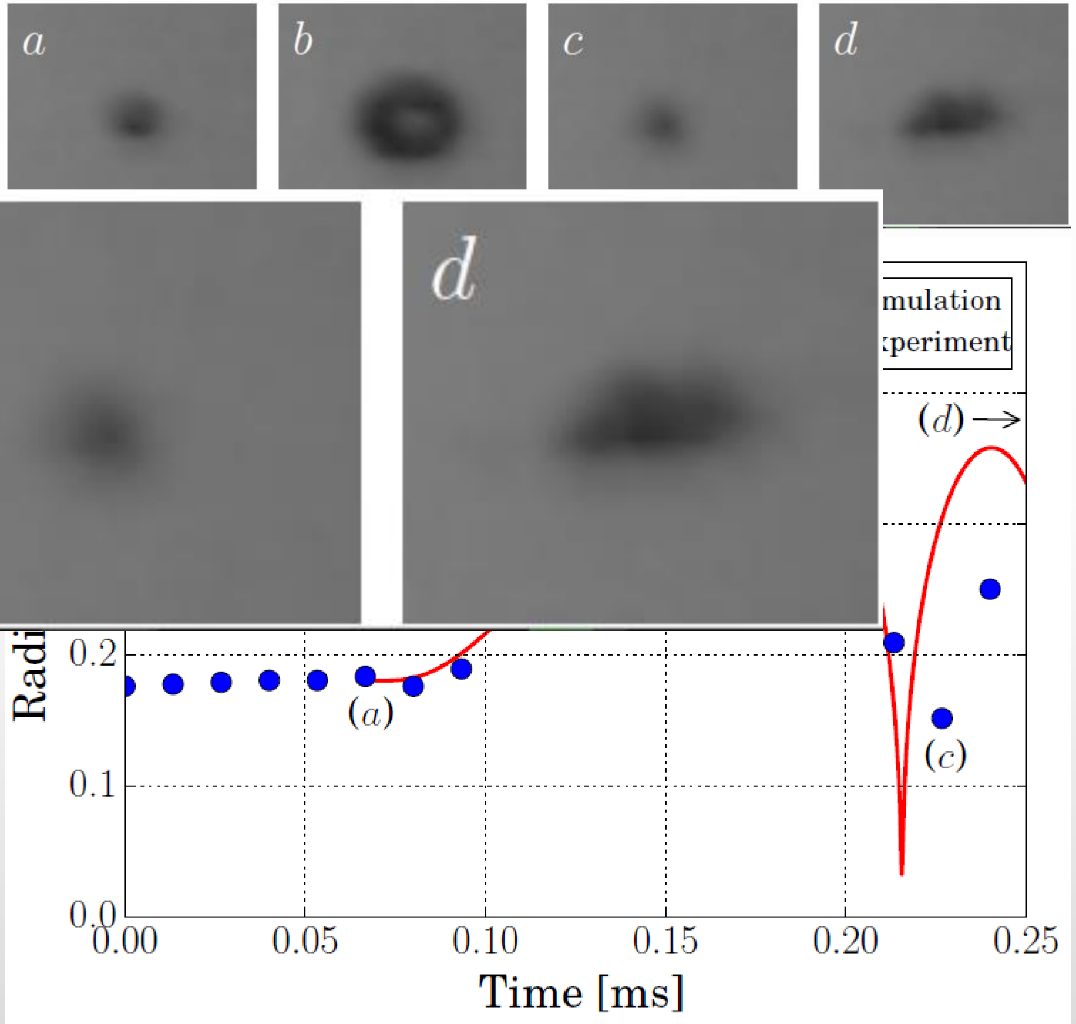
Results

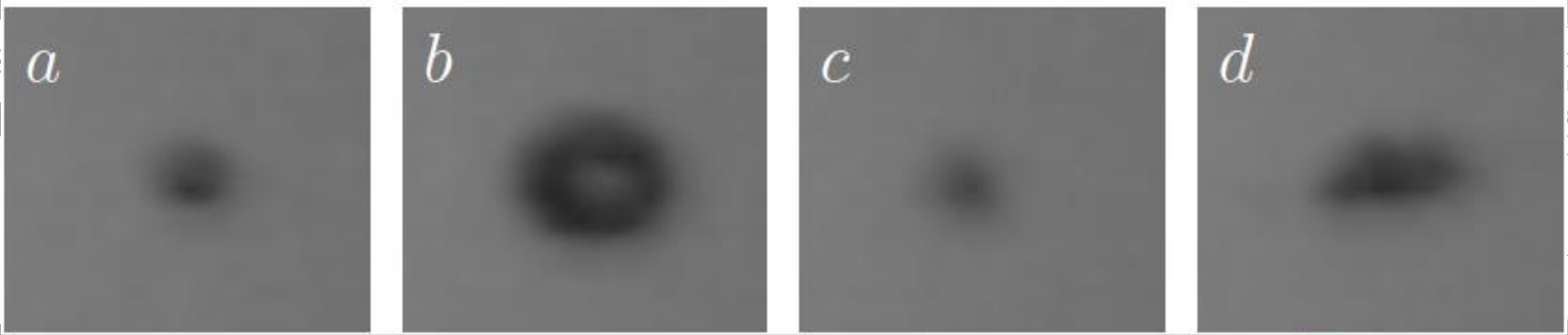




We can see how bubbles start to expand near the bottom and shink near the free surface

Results



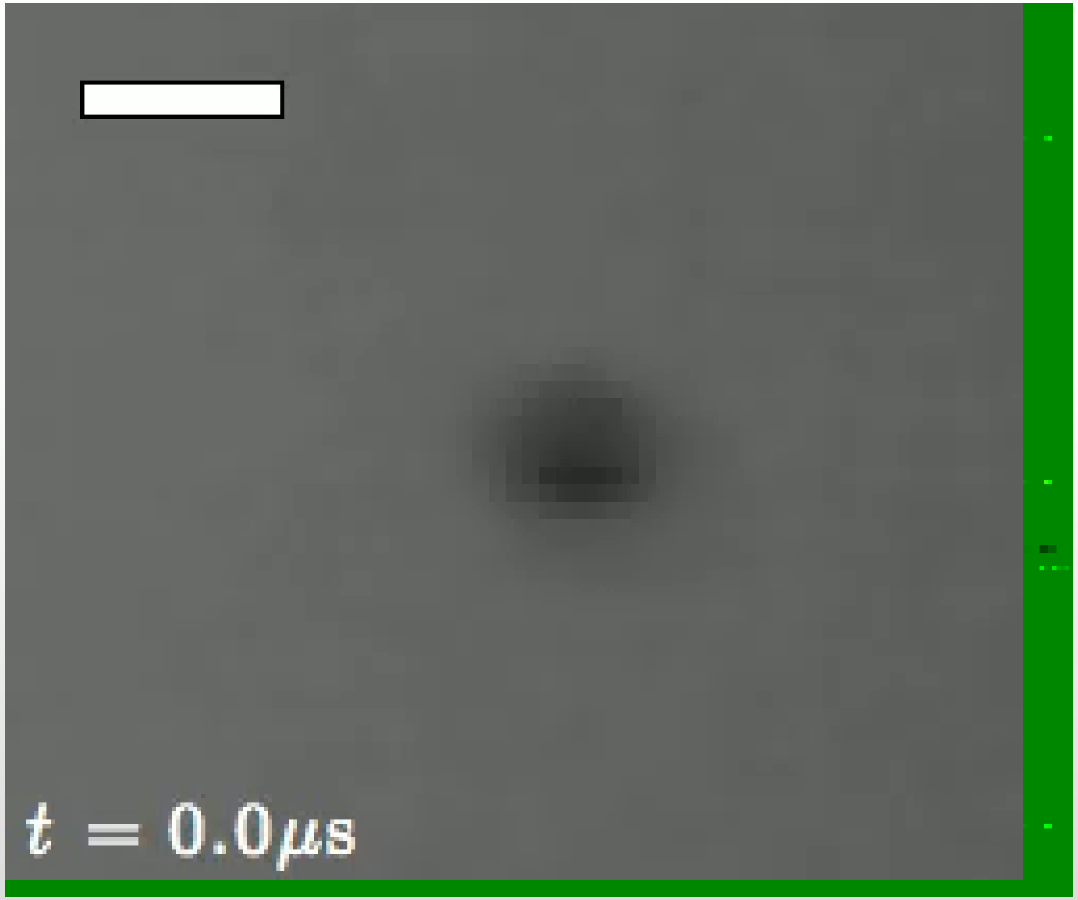


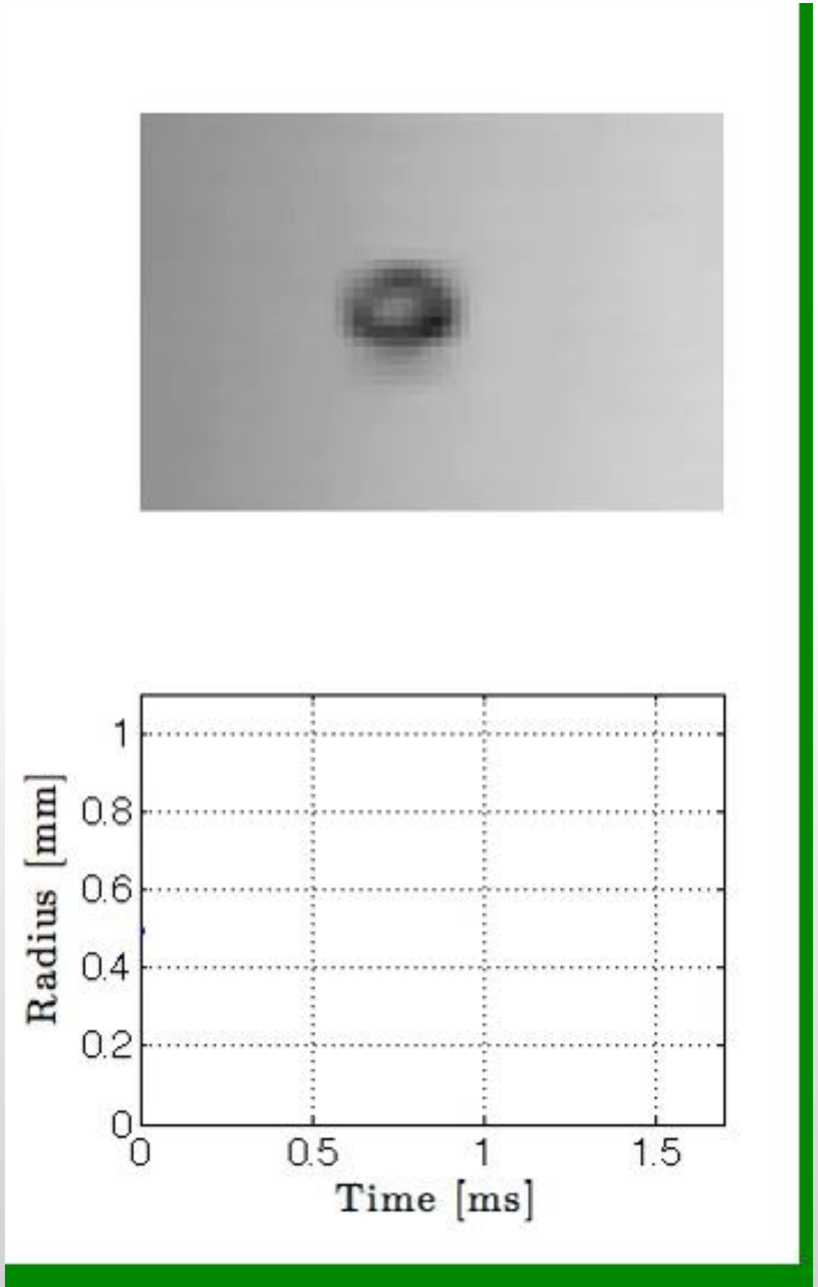
- Th... las... liq...

- The Rayleigh-Plesset equation has been integrated numerically for a bubble, but as we can see it can't describe after t ≈ 0.22 ms since it's valid for a single bubble;

- The number of fragments cannot be measured due to the high void fraction of the resulting bubble cloud.

Results





Results

- The number of fragments N is estimated using the model of Brennen:

$$n_m = \frac{1}{3}\left((7+\Gamma_m)^{1/2} - 2\right)$$

$$N \approx {n_m}^3 \approx 10^6$$

$$\Gamma_m = \rho R^2 \ddot{R}/\sigma$$

ρ : fluid density
σ : liquid-gas surface tension
R : minimum radius

- The fast bubble colapse and breakup causes an increase in the total gas-liquid interfacial area by a factor of the order of $N^{1/3}$;

- This increase leads to a rapidly grow of the bubble fragments in the cloud by diffusion of carbonic gas into them;

Results

- Assuming that the cloud grows as the sum of its componentes, the cloud size, L_c:

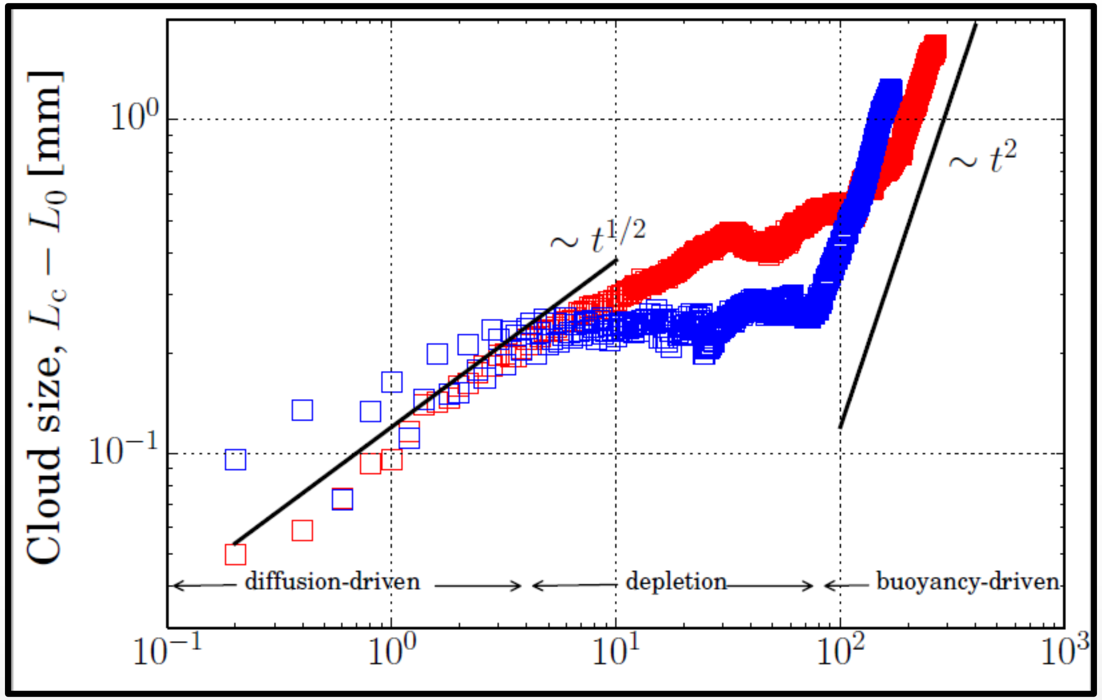
$$L_c = L_0 + \alpha N^{1/3} F\left(\frac{\Delta C}{\rho_g}\right)\sqrt{\frac{\kappa t}{\pi}}$$

ΔC : difference between the concentration of carbonic gas in the bulk and the saturation
α : dimensionless constant
ρ_g: gas density inside the bubble
κ: diffusivity of the gas
$F(x)$: known function

- With $N \approx 10^6$, the radius of the bubble cloud is expected to grow about 100 times faster than a single bubble with same volume;

Results

$$L_c - L_0 = \alpha N^{1/3} F\left(\frac{\Delta C}{\rho_g}\right)\sqrt{\frac{\kappa t}{\pi}}$$



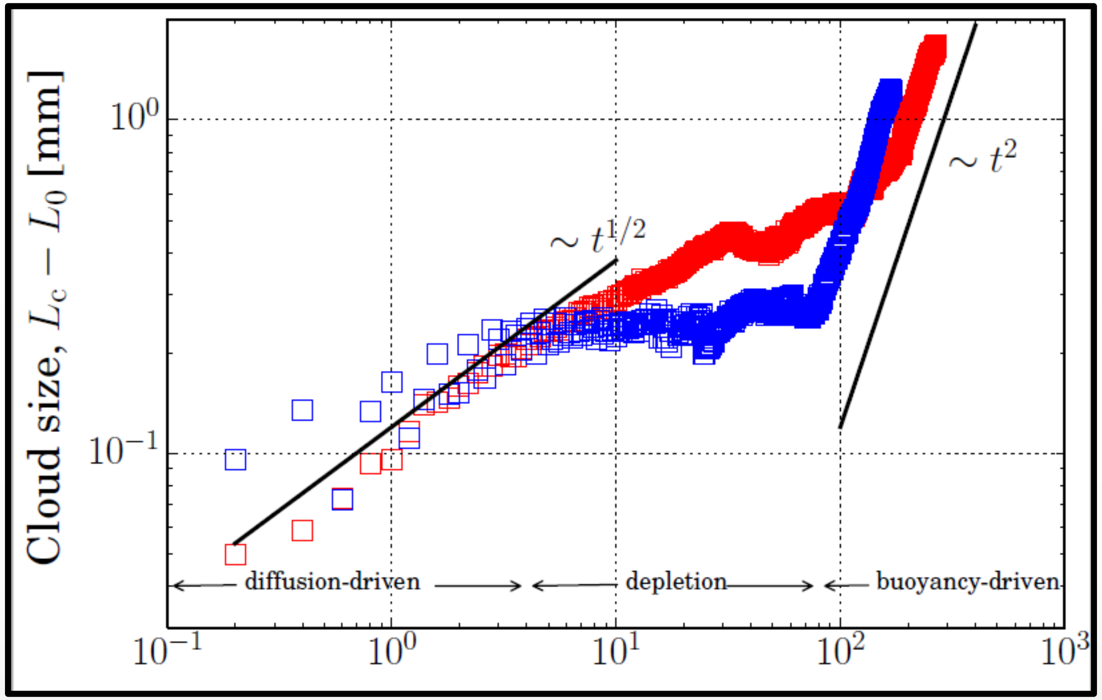
- At short time, there is cycles of expansion and compression waves that causes flutuations in the shock-induced collapse;

- To avoid this noise, they performed experiments creating bubble cloud with a laser-induced implosion;

- This bubble cloud generated by laser-induced cavitation initially grows as $t^{\frac{1}{2}}$ like a pure diffusive growth;

Results

$$L_c - L_0 = \alpha N^{1/3} F\left(\frac{\Delta C}{\rho_g}\right)\sqrt{\frac{\kappa t}{\pi}}$$



Diffusion-driven

Stage where the bubble fragments in the cloud grow rapidly as a result of the diffusion of carbonic gas into the newly created cavities. This growth representes the upper bound, since the center ones receive less CO_2

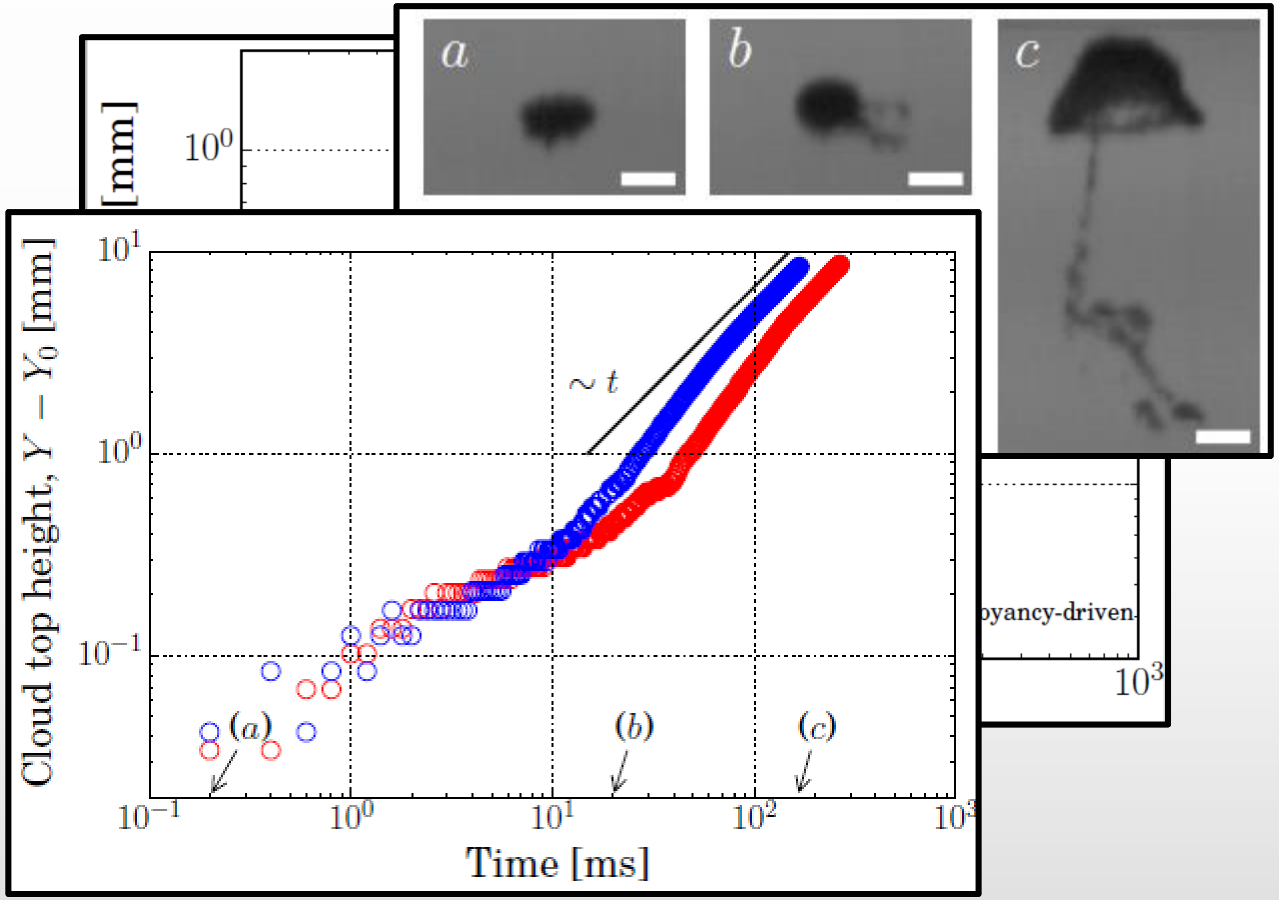
Depletion

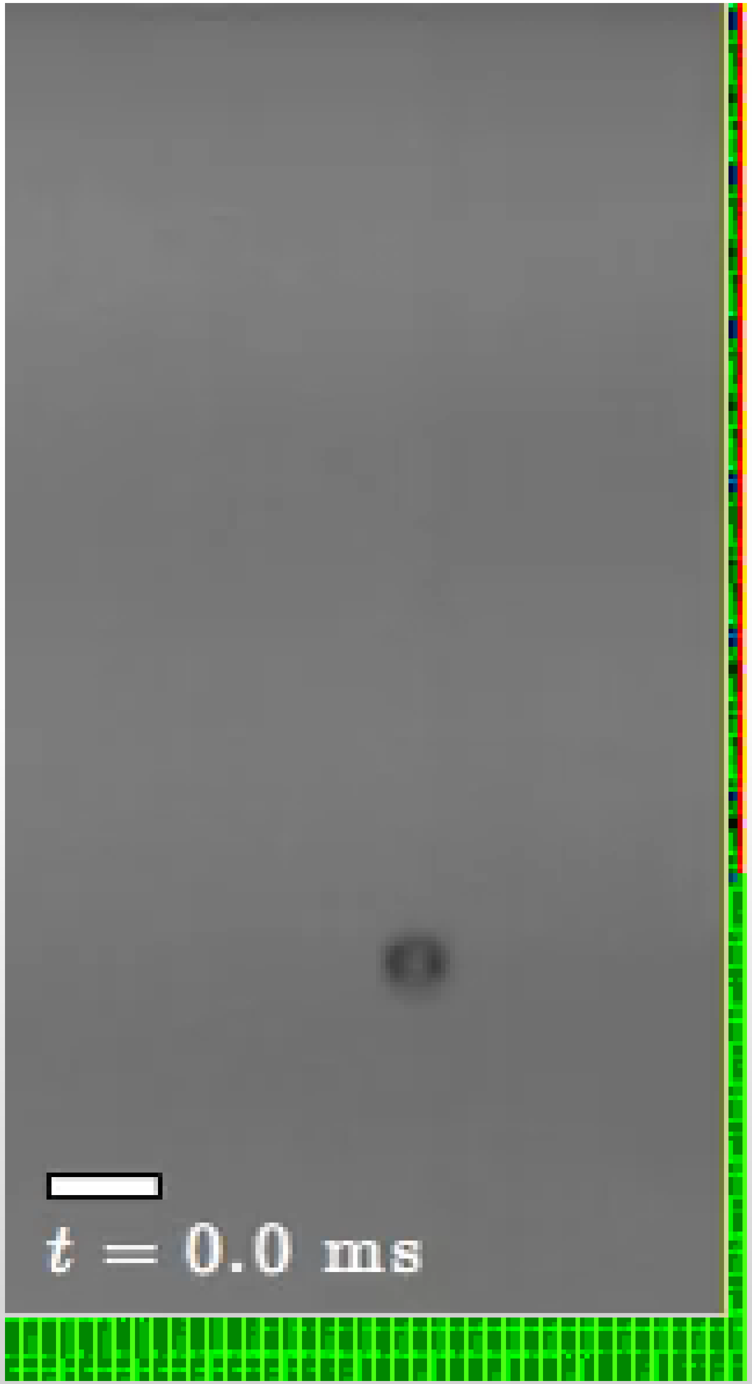
When the carbon dioxide is locally depleted, around $t \approx 10$ ms, the growth of cloud's size became more moderated

Buoyancy-driven

The rapidly growing bubble clusters acts as buoyance sources that lead to formation of bubble-laden buoyant vortex ring. As the vortices rise, their vortical motion contributes to enhance the transport of CO_2 to the bubbles.

Results

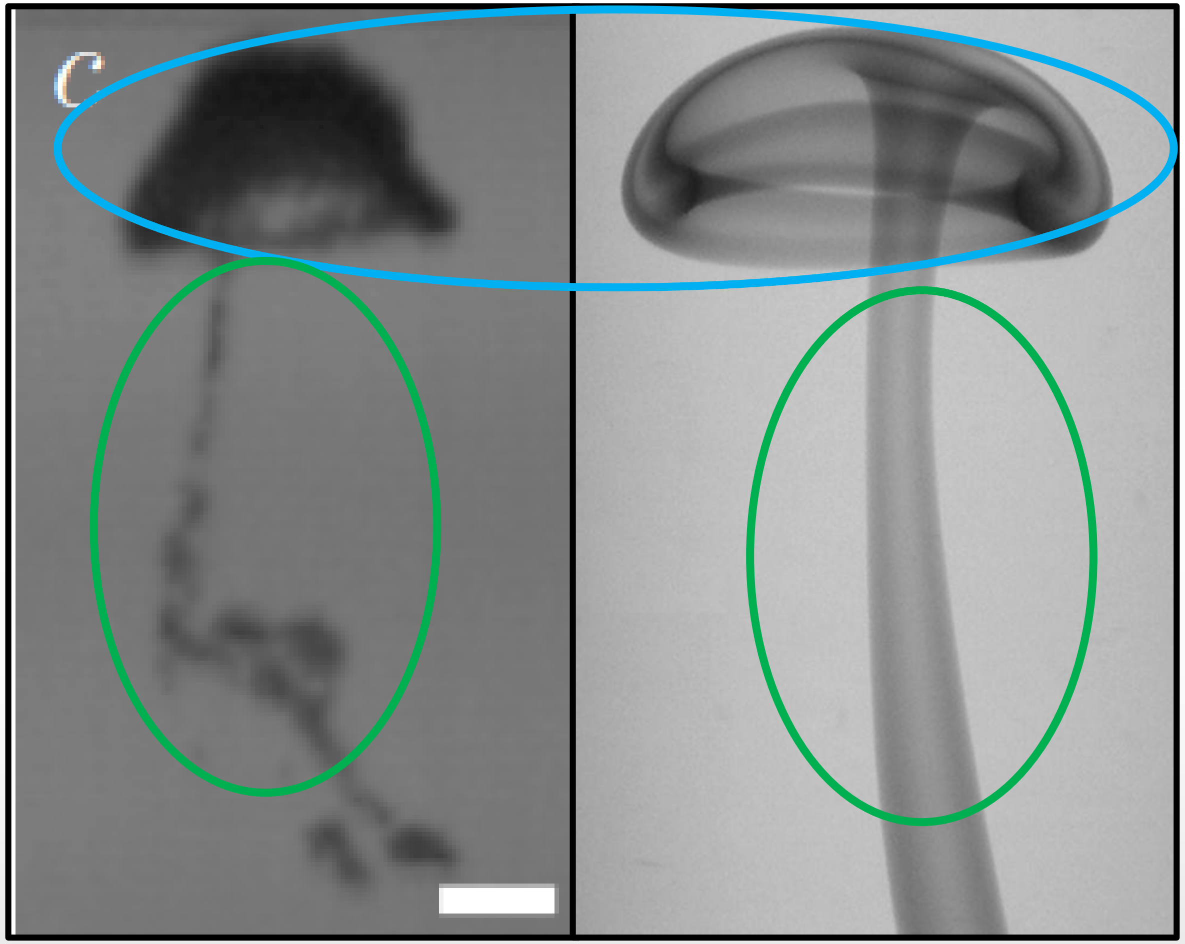




As a consequence of the continuous generation of gas volume inside the vortex, the rising velocity approaches a constat value

Results

- This behavior is similar to that found in the so-called autocatalytic vortex rings or plumes;
- This analogy extends to their morphology;
- The plume is a vortex with a nearly spherical cap with a thin conduit that ascends more slowly;

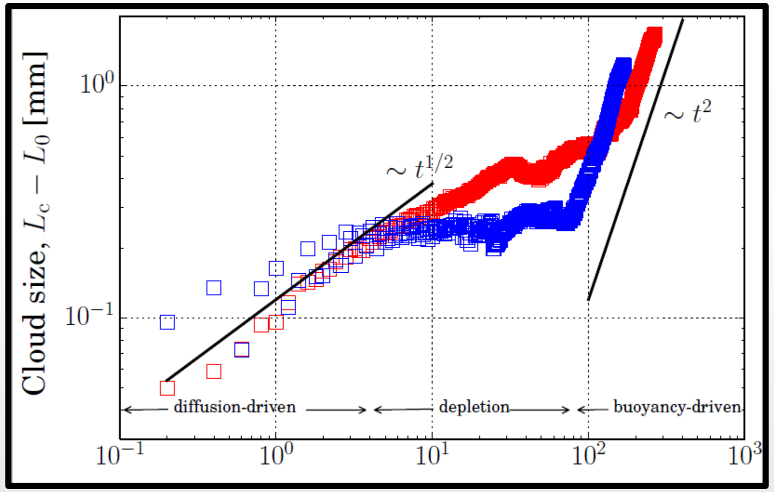


[Autocatalytic plume produced by IAA reaction]

- This stage is the most effective in terms of liquid outgassing because of its accelerating nature;

Conclusions

- The behavior of the bubble-laden vortex rings during the diffusion-driven and buoyancy-driven stages is independent of the mechanism used to generate the initial bubble cloud;
  - Same scaling laws for laser-induced cavitation and pressure-induced bubble implosion;



- The observation Suggests that the plume's dynamics does not seem to depend on a particular initiation mechanism;

- The dynamics of these bubble-laden self accelerating plumes moving in supersaturated media may partly explain the explosive behavior of systems like limnic and explosive volcanic eruptions where the current models tipically neglect the role of these autocatalytic structures;

Conclusions

- There is two side effects induced by the development of bubbly plumes relevant to the global degassing process in the bottle:

1. The finite size of the conteiner generates a global recirculation motion that drags bubble from the free surface to bulk;

2. The flow induced inside also speeds up the growth of gas cavities in the walls that would only grow by diffusion;

THANK YOU!