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On the crown forming instability in the drop splash problem

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The motivation

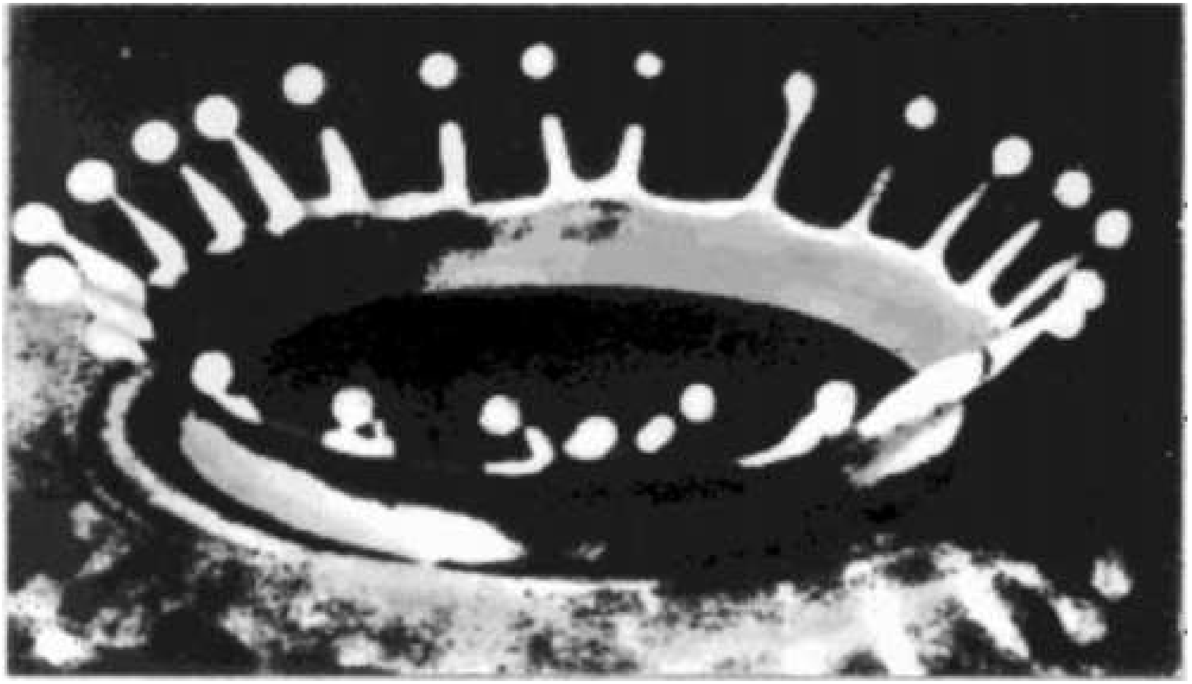

Figure: the famous milk crown of Edgerton & Killian (1954).

Original question[†]: "Why there are exactly 24 spikes in the above photo?"

General question: "What is the nature of the crown forming instability?"

[†]S. P. Betyaev, *Physics Uspekhi* **38**, 287–316 (1995)

Outline

- A bit of history
- Problem set-up
- *Milk* as an experimental material
- Experimental results:
  - Crown formation picture
  - Regularity types of the crown
  - Instability mechanism
  - Bifurcation phenomena
  - Milk vs. water
- Conclusions

A bit of history: existing theories

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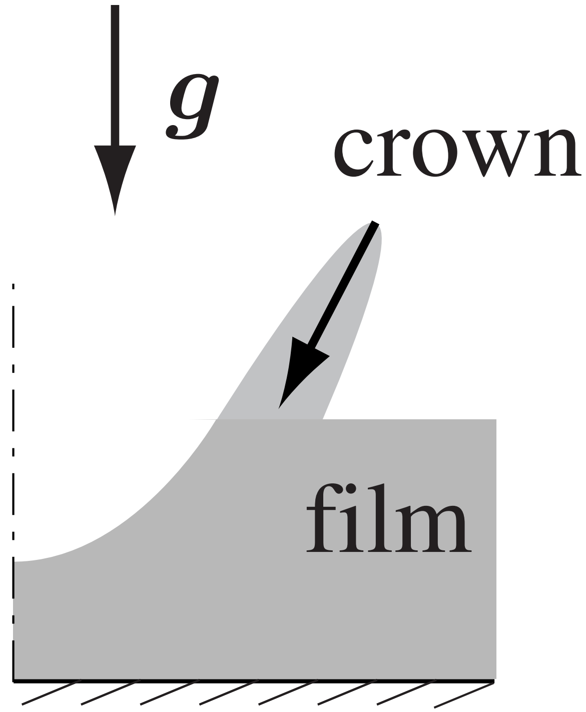
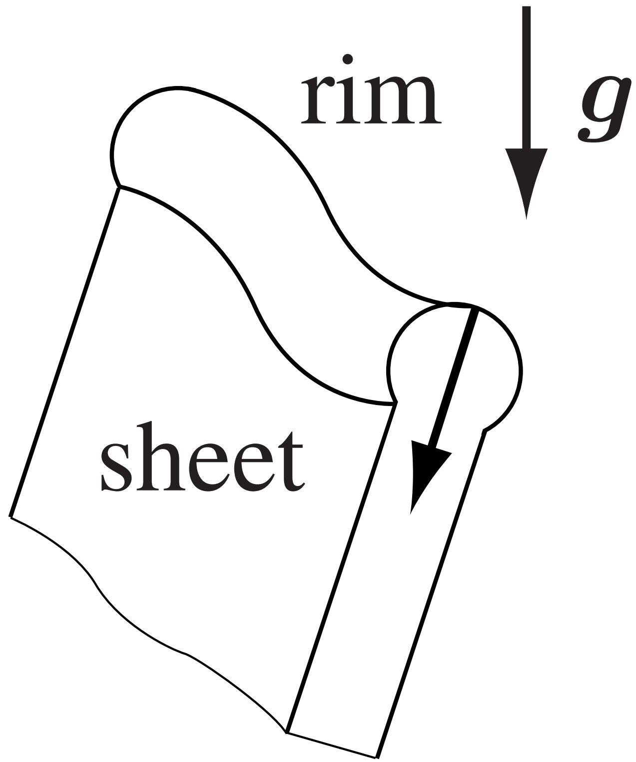
- The Rayleigh-Taylor instability (Allen, 1974).



Deceleration of an interface

A bit of history: existing theories

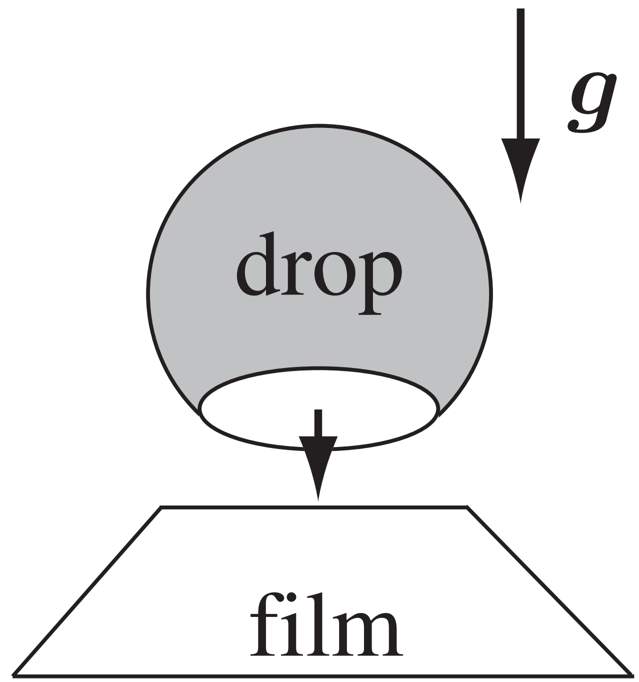
- The Rayleigh-Taylor instability (Allen, 1974).
- The Plateau-Rayleigh instability (Fullana & Zaleski 1999, Roisman *et al.* 2006).



Disintegration of a retracting rim

A bit of history: existing theories

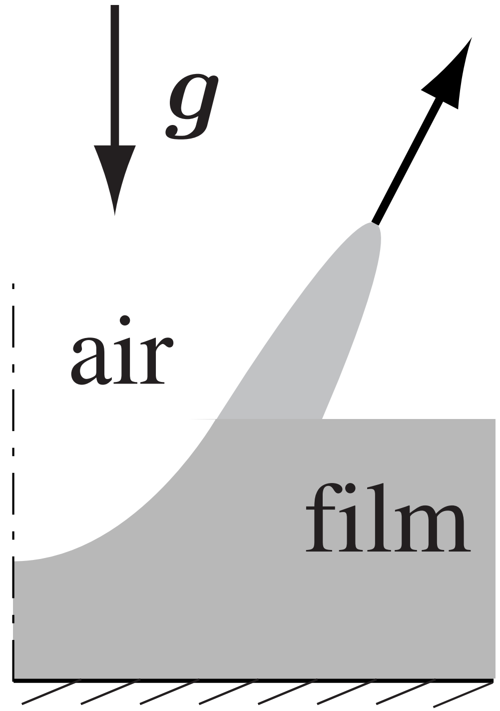
- The Rayleigh-Taylor instability (Allen, 1974).
- The Plateau-Rayleigh instability (Fullana & Zaleski 1999, Roisman *et al.* 2006).
- Another Rayleigh-Taylor instability (Thoroddsen & Sakakibara 1998).



Deceleration of the lower drop surface

A bit of history: existing theories

- The Rayleigh-Taylor instability (Allen, 1974).
- The Plateau-Rayleigh instability (Fullana & Zaleski 1999, Roisman *et al.* 2006).
- Another Rayleigh-Taylor instability (Thoroddsen & Sakakibara 1998).
- The Kelvin-Helmholtz instability (Yoon *et al.* 2007).



Shear
at the interface

A bit of history: existing theories

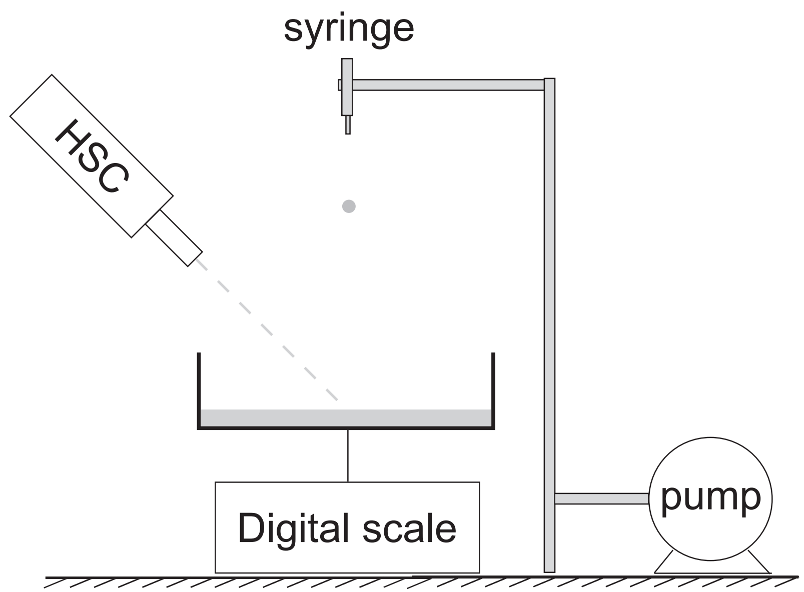
- The Rayleigh-Taylor instability (Allen, 1974).
- The Plateau-Rayleigh instability (Fullana & Zaleski 1999, Roisman *et al.* 2006).
- Another Rayleigh-Taylor instability (Thoroddsen & Sakakibara 1998).
- The Kelvin-Helmholtz instability (Yoon *et al.* 2007).
- **Question**: which one is relevant?

Problem set-up

Governing parameters:

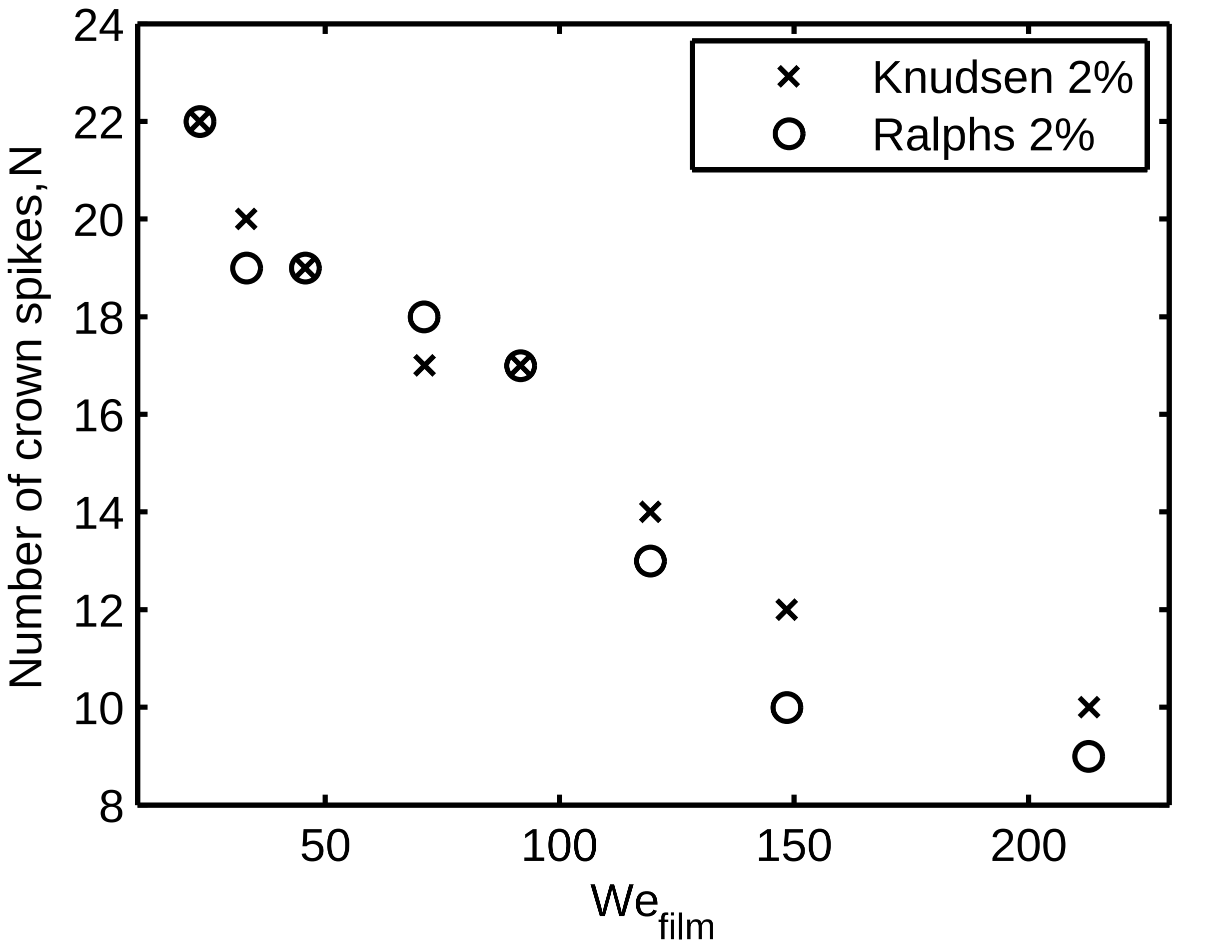
- $\boxed{We_{\mathrm{drop}}} = \dfrac{\text{inertia}}{\text{surface tension}} \simeq (0.6 - 14) \times 10^2$
- $Oh = \dfrac{\text{viscosity}}{\text{surface tension}} \simeq (0.15 - 0.41) \times 10^{-2}$
- $\alpha = \dfrac{\text{drop inertia}}{\text{film inertia}} \simeq 0.1 - 10.0$
  or $\boxed{We_{\mathrm{film}}} = \alpha^{-1} We_{\mathrm{drop}}$

Experimental set-up:



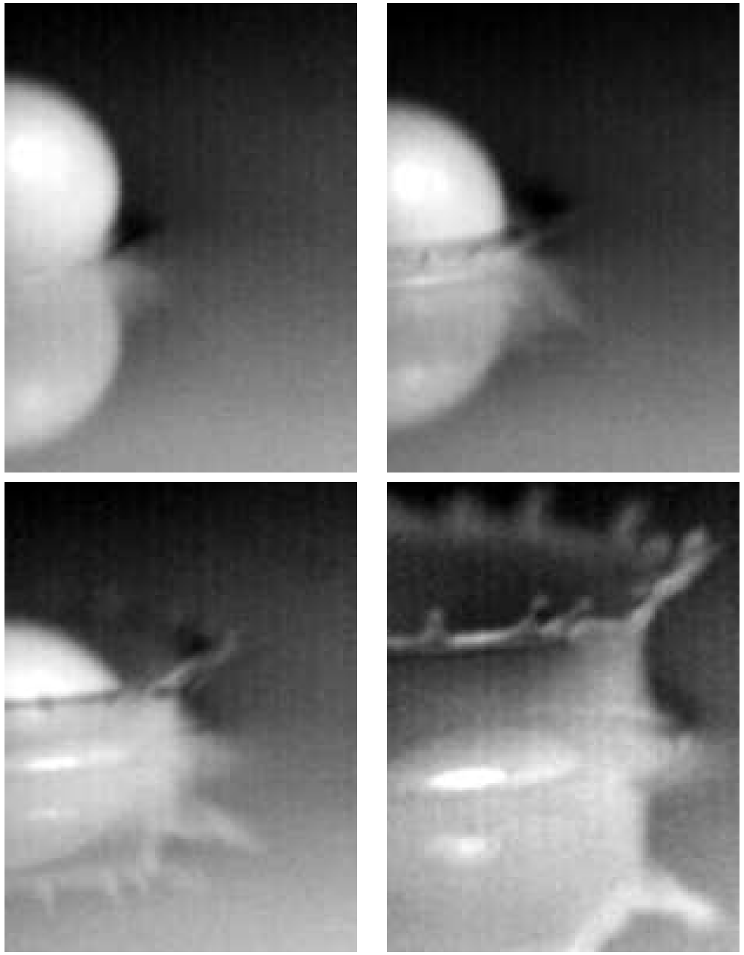
Working fluids: *water* and *milk*

Milk as an *experimental* material

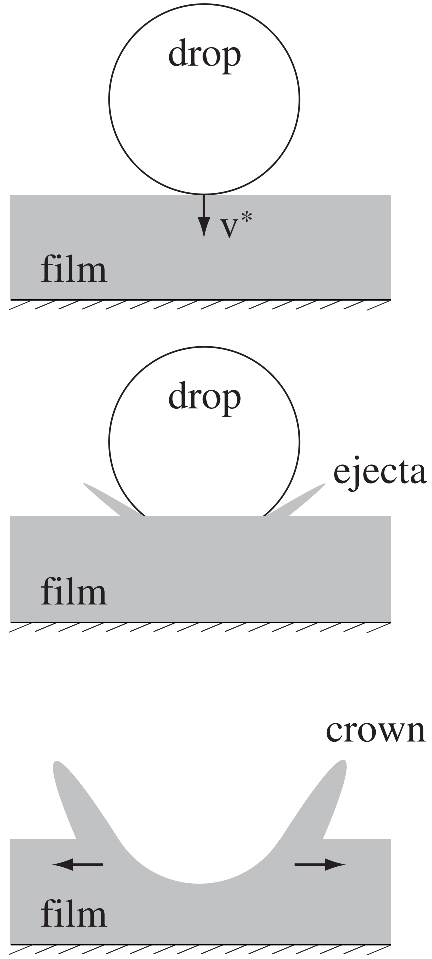


Comparison of two milks; release height is 16.51 cm.

Experimental results: crown formation



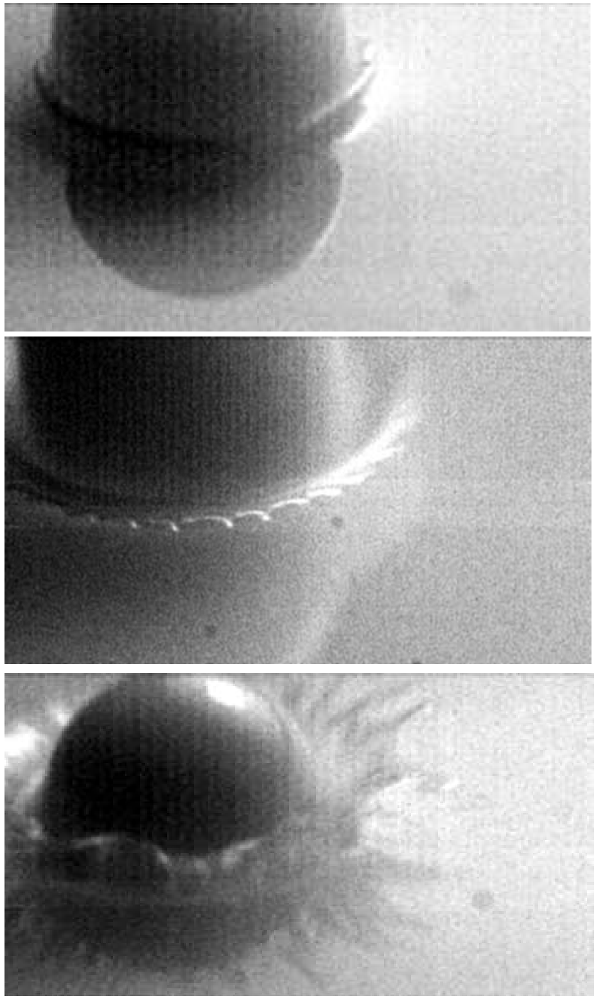
From ejecta to crown; time interval $t = 1610\,\mu\mathrm{s}$.



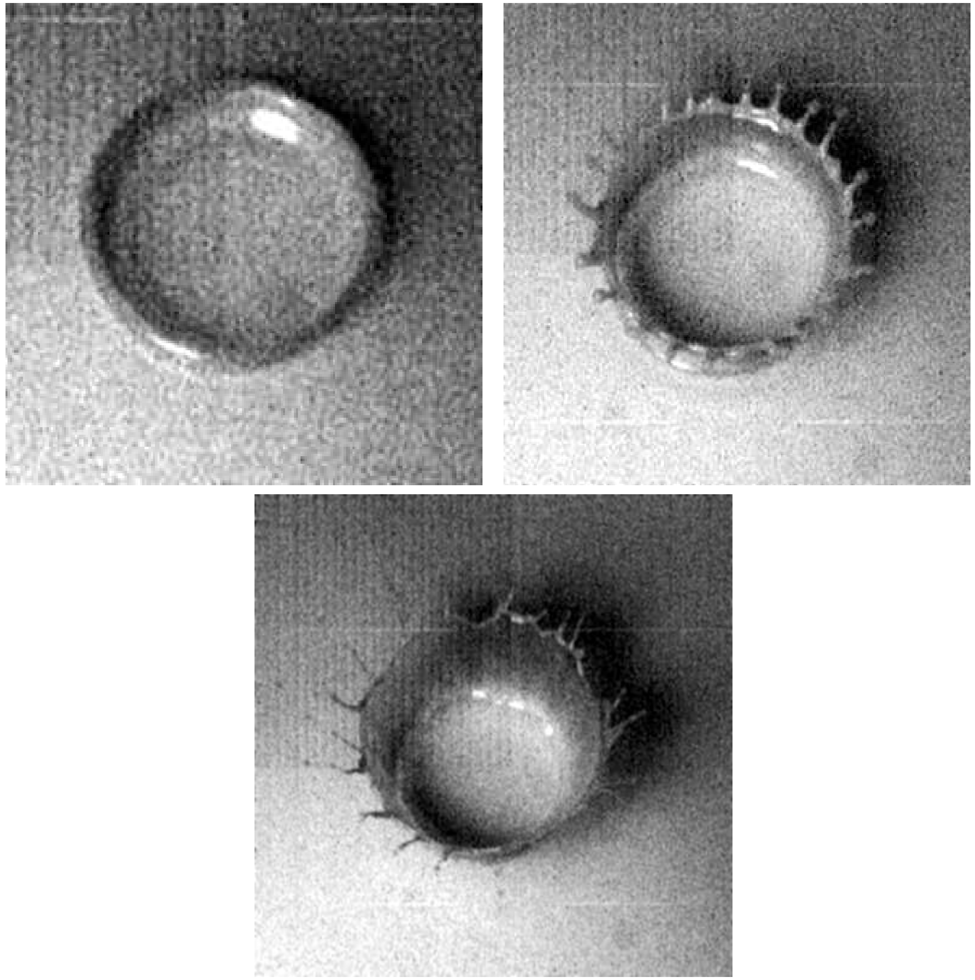
Three key elements of the drop splash.

Experimental results: crown regularity

Three modes of a crown formation



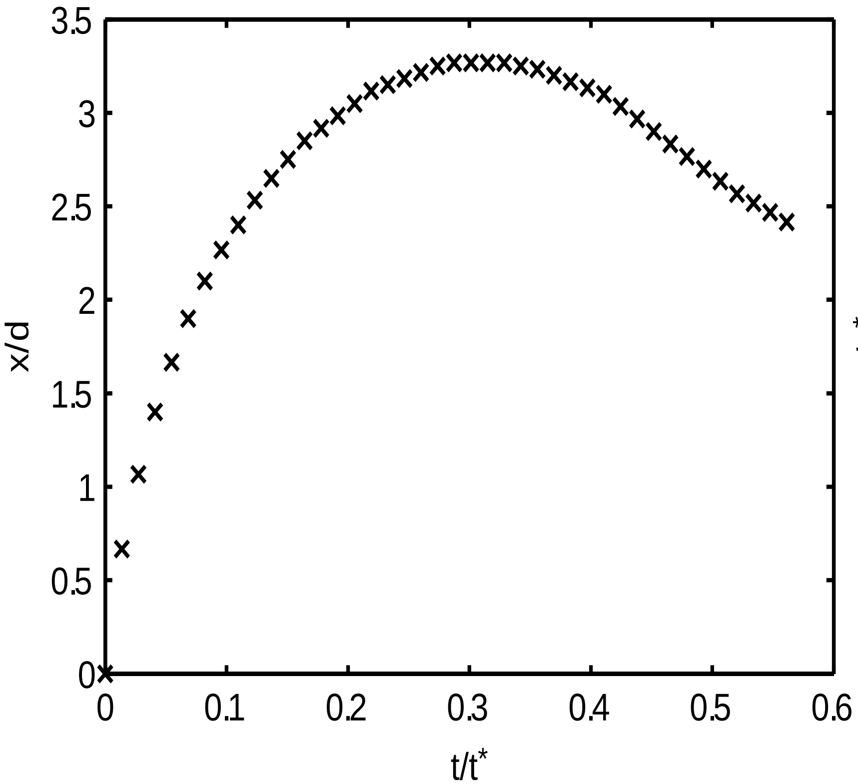
Early stages

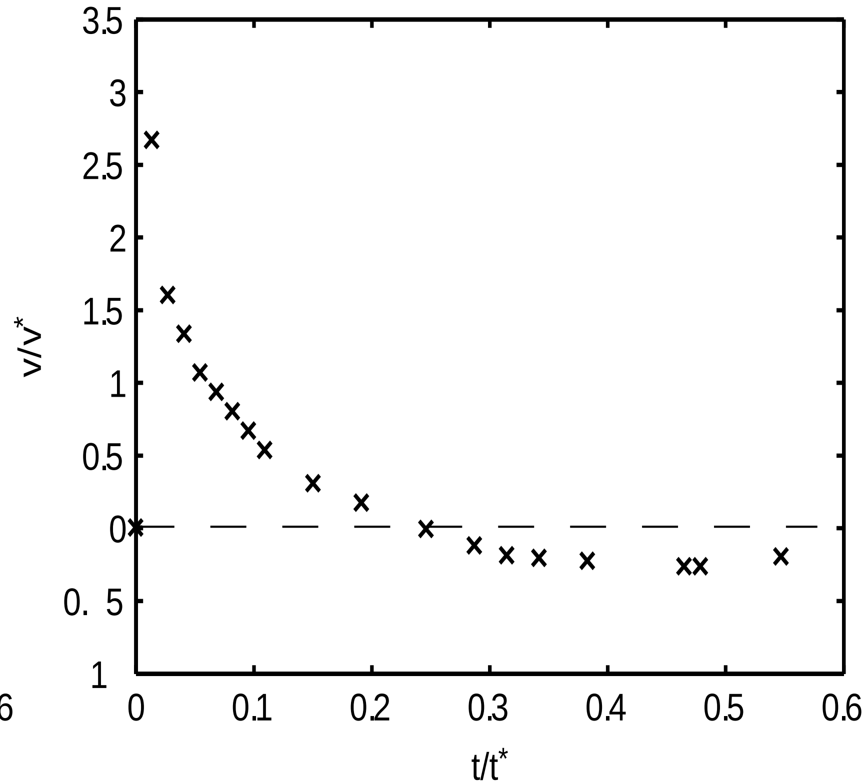


Late stages

Experimental results: instability type

Kinematics; peak values $a \sim 10^5\,\mathrm{m/s^2}$, $v \sim 10\,\mathrm{m/s}$





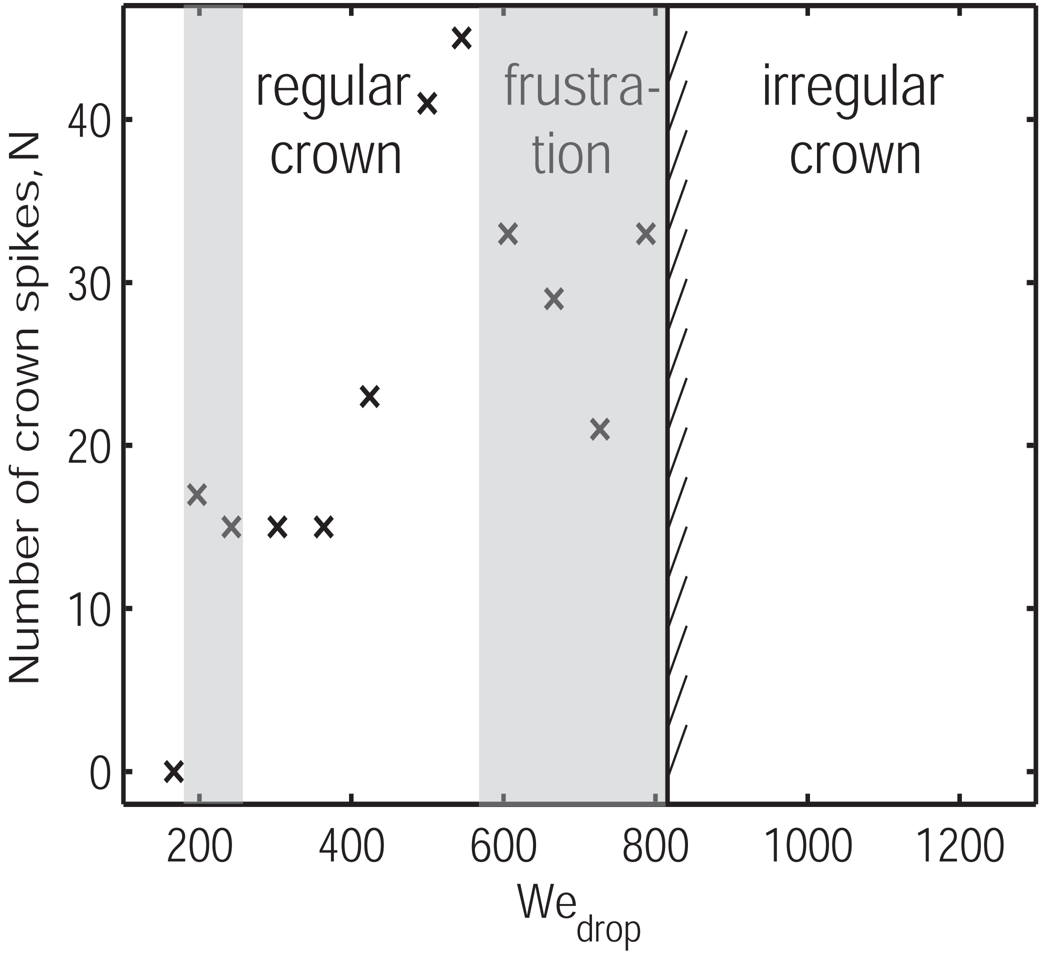
Displacement† Velocity†

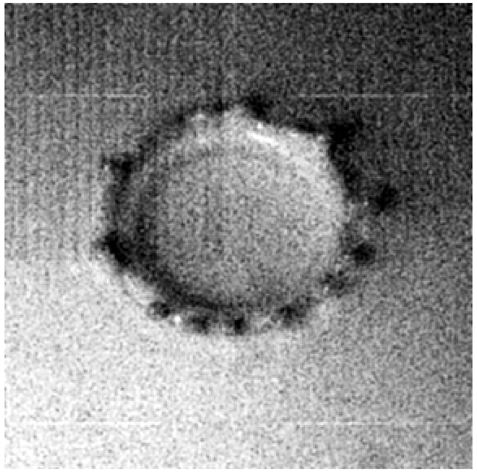
Conclusion: this is the Richtmyer-Meshkov instability

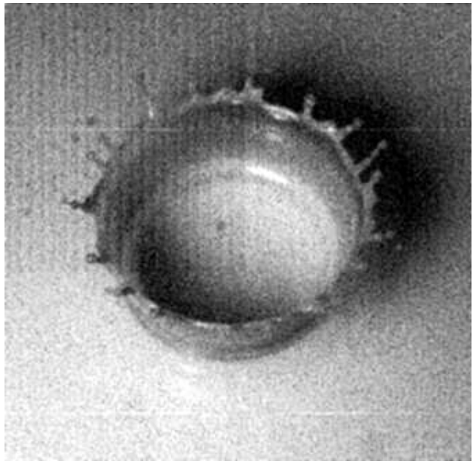
† $t^* = \sqrt{d^3\rho/\sigma}$, $v^* = \sqrt{2gH}$.

Experimental results: bifurcations

Transitions between three regularity types





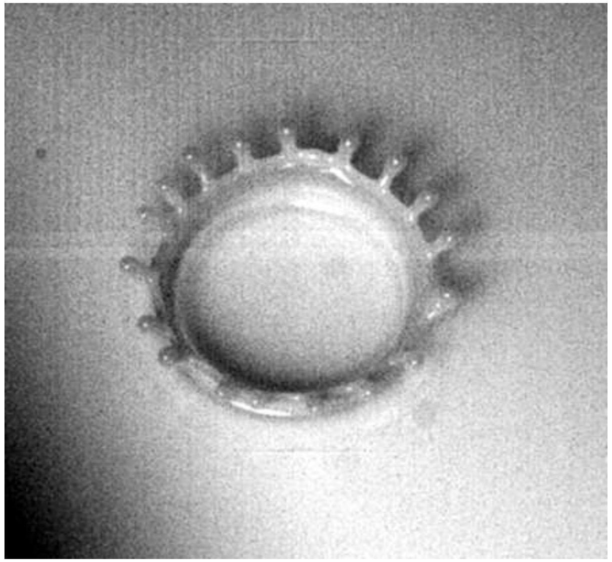


Intermittency phenomena

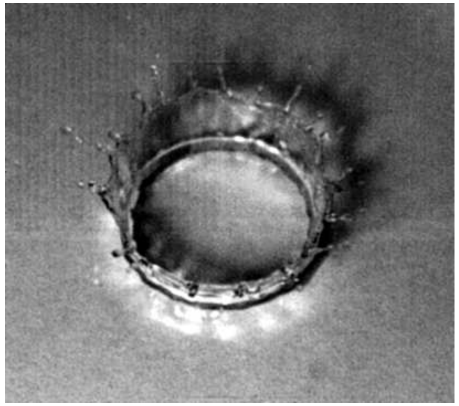
Frustration

Experimental results: milk vs. water

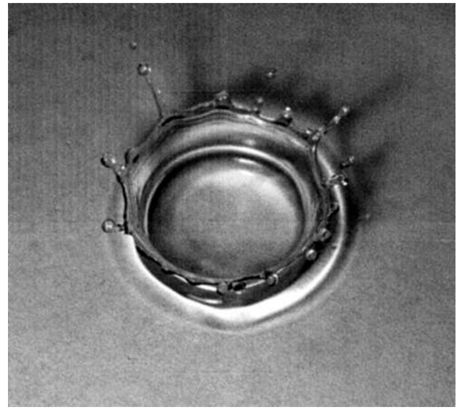
Effects of surfactants (SDS) and viscosity



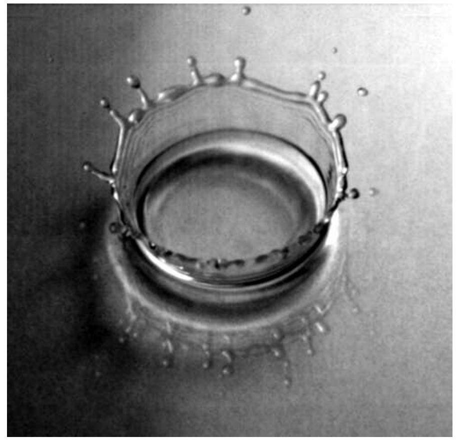
Milk crown



Water crown



SDS crown



Glycerol crown

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- The crown spike distribution is controlled by the very early stages of ejecta formation through the *Richtmyer-Meshkov* instability mechanism.
- The reasons which make the milk crown so distinctive are pointed out.