Meeting on Numerical Challenges in Two-Phase Flows

On the experimental validation of Gerris for singular capillary flows

J. M. Montanero

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Summary

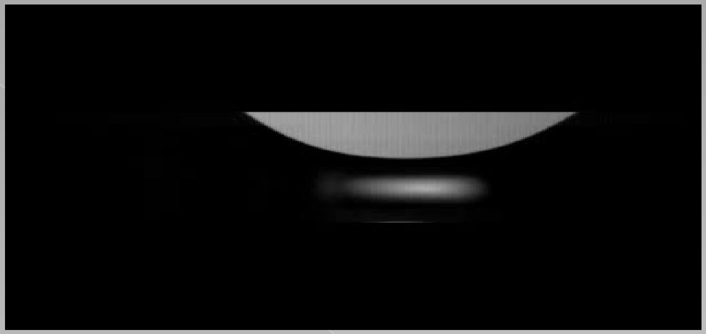
- A challenge for VoF methods: the simulation of singularities in capillary flows

- Experimental validation: The optical imaging method

- An example: Tip streaming in electrified drops

Singularities in capillary flows

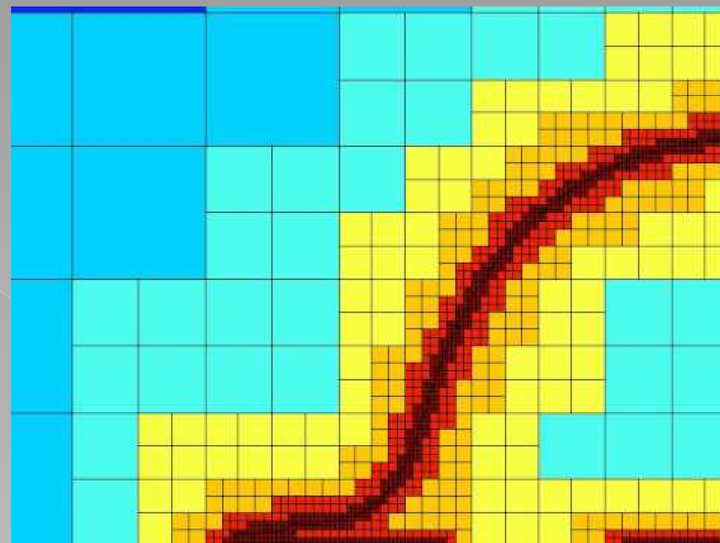
The most common example: the pinching of the free surface



- It occurs in a finite time
- At the pinching point:
  - The velocity field, viscous stresses, and capillary pressure diverge
  - The characteristic length goes to zero

Disparity of between global and local time and length scales

The interface numerical diffusion



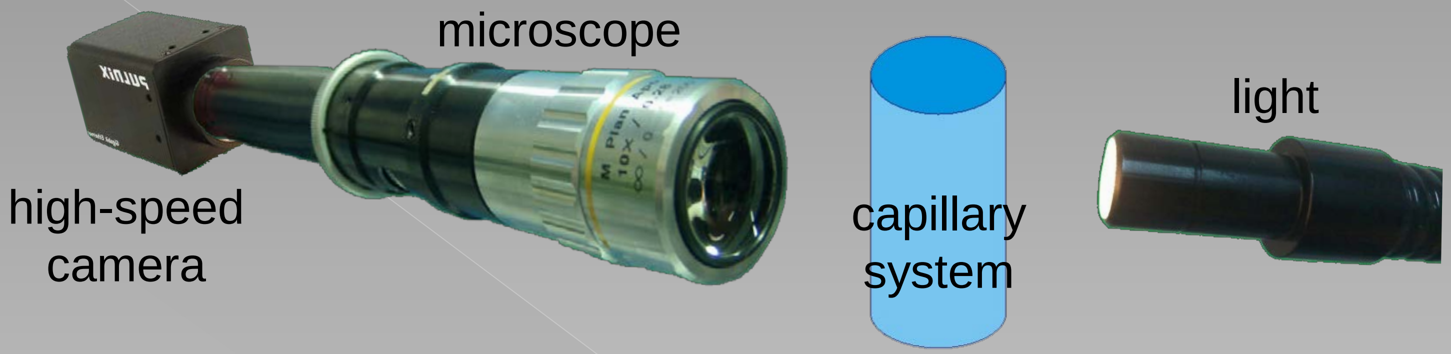
http://www.digplanet.com/wiki/Adaptive_mesh_refinement

Numerical diffusion, curvature calculation, … become important factors in capillary singularities

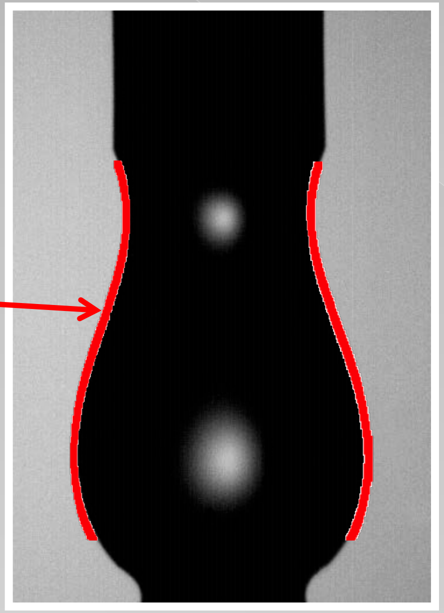
For instance, it may affect both the size and monodispersity of drops, bubbles, and capsules, produced in the jetting regime…

Quantitative experimental validation becomes neccesary

Optical imaging



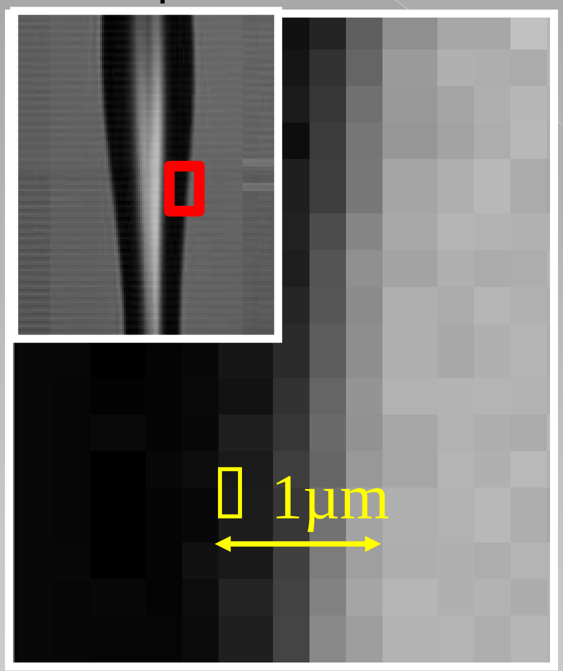
Sub-pixel image processing technique



Resolution
- Temporal: 10^6 fps
- Spatial: 100 nm

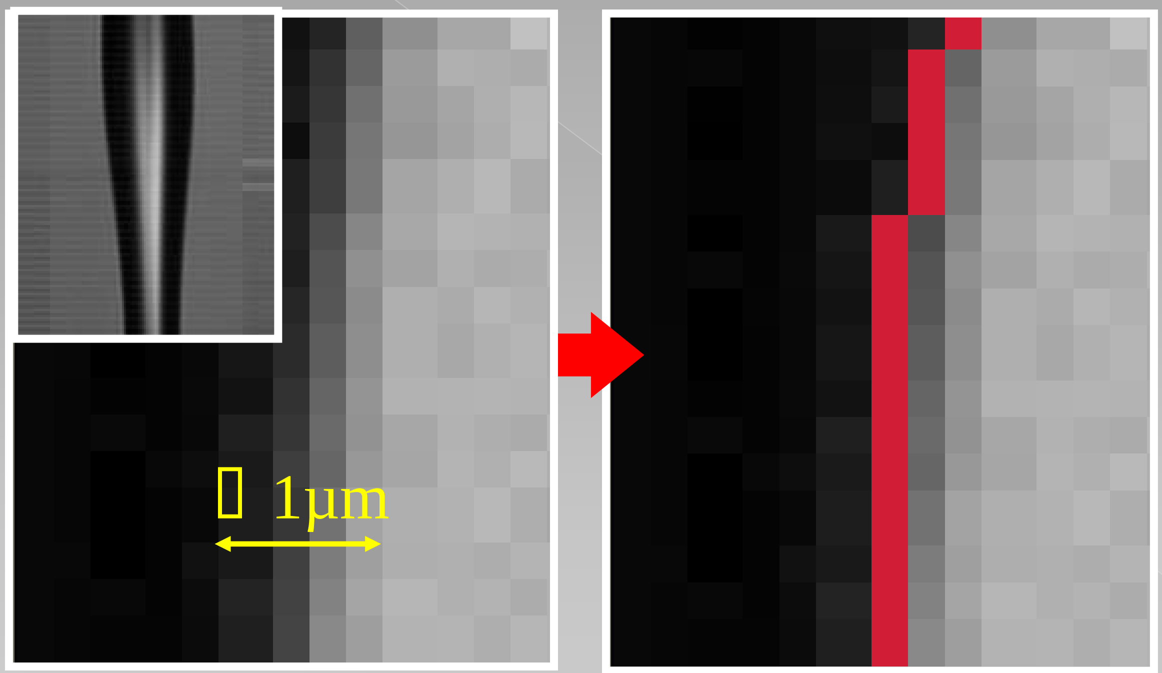
Image processing technique

“Optical difusion”



Digital image

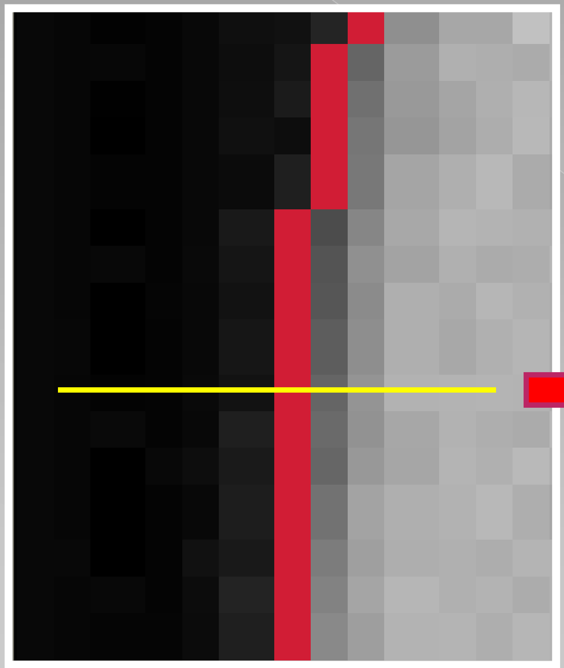
Image processing technique



Digital Image

Pixel level
(Otsu´s method)

Image processing technique



Pixel level
(Otsu´s method)

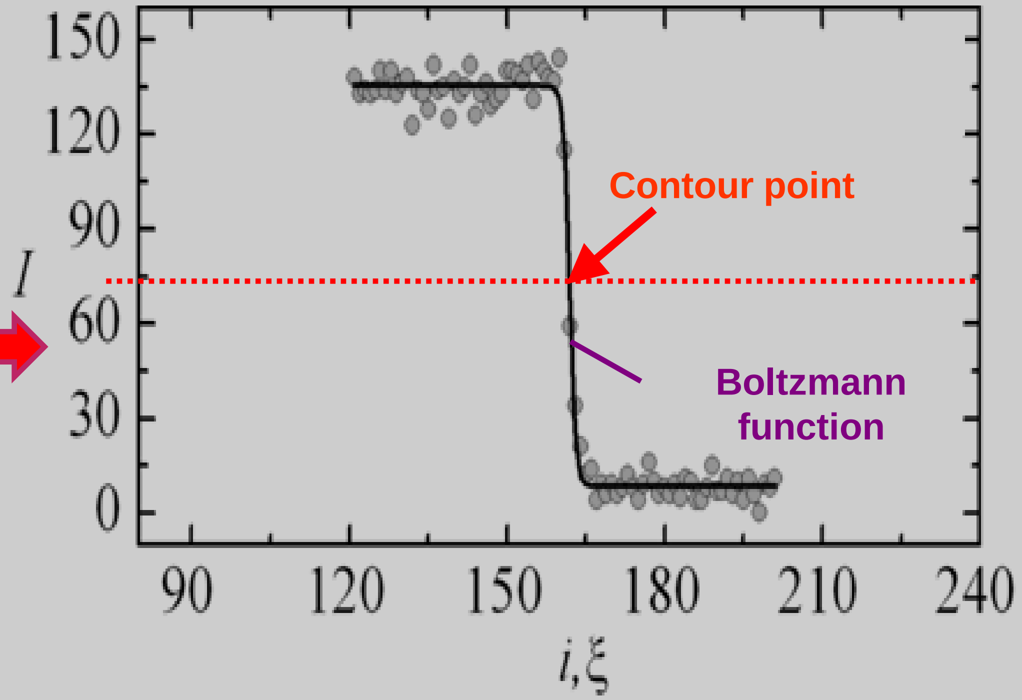
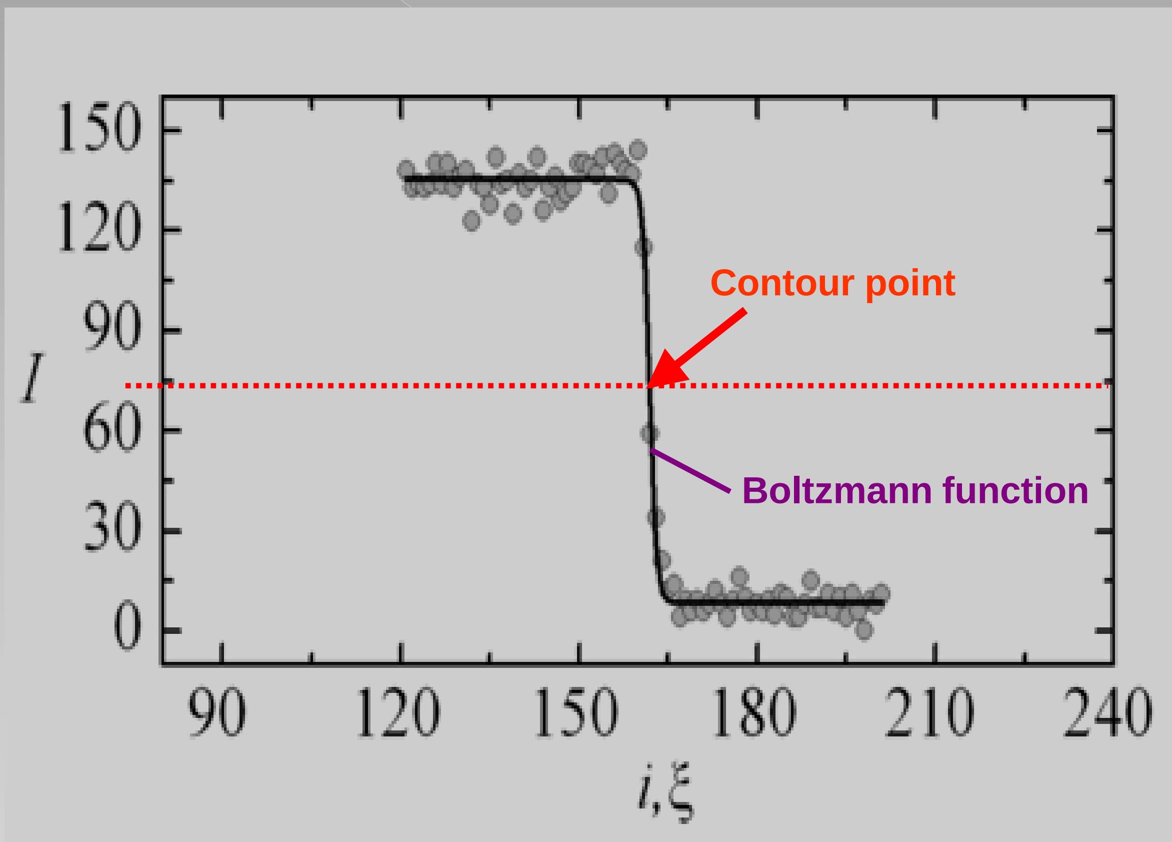
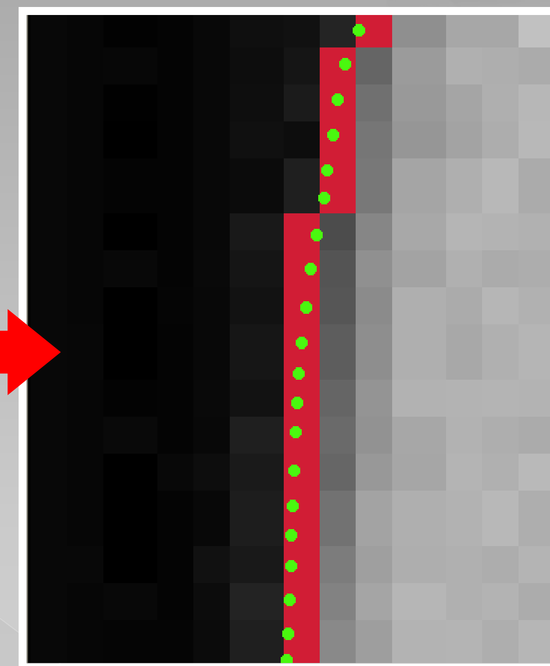


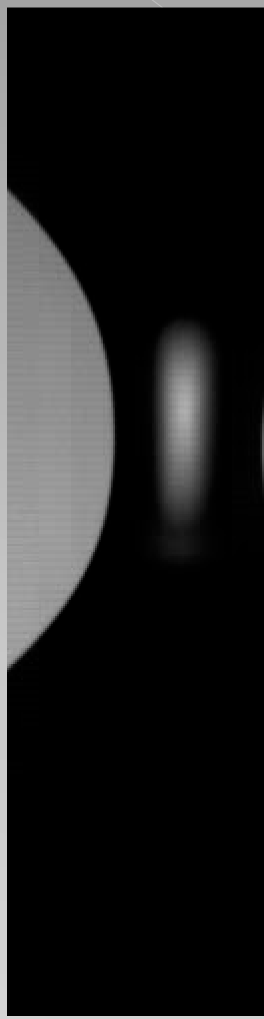
Image processing technique





Subpixel level

Image processing technique



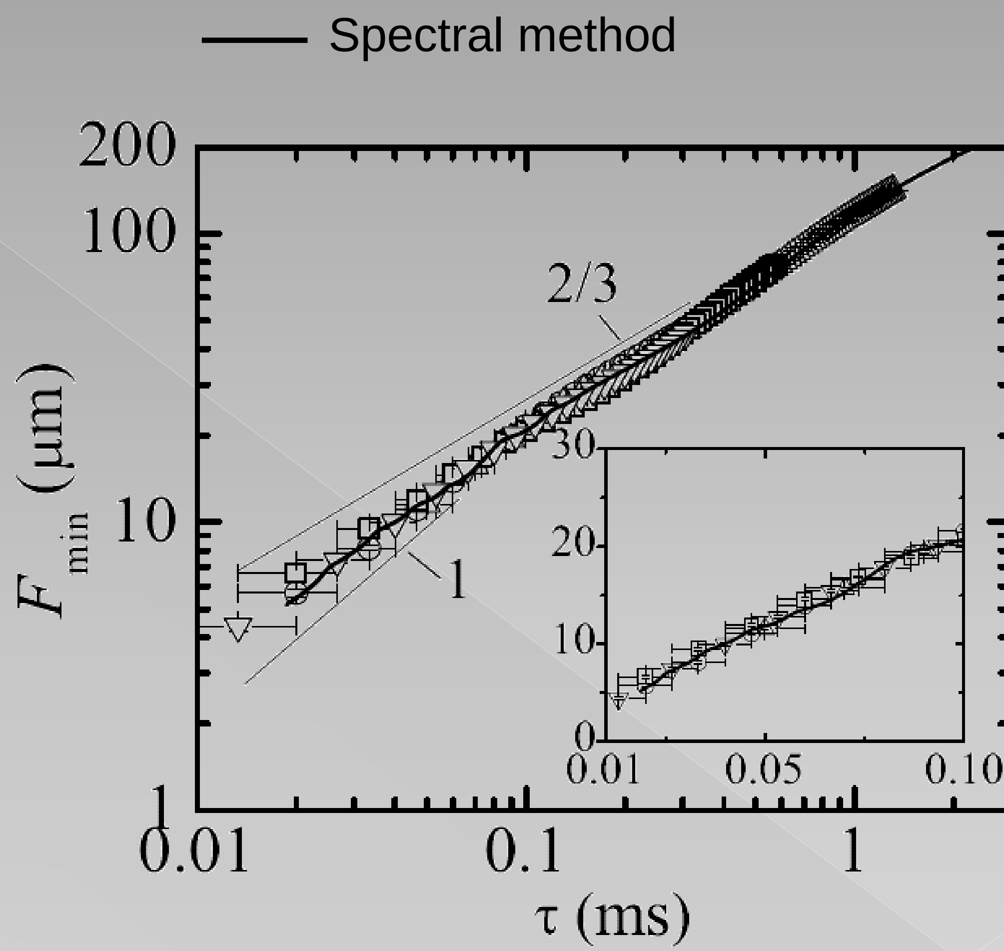
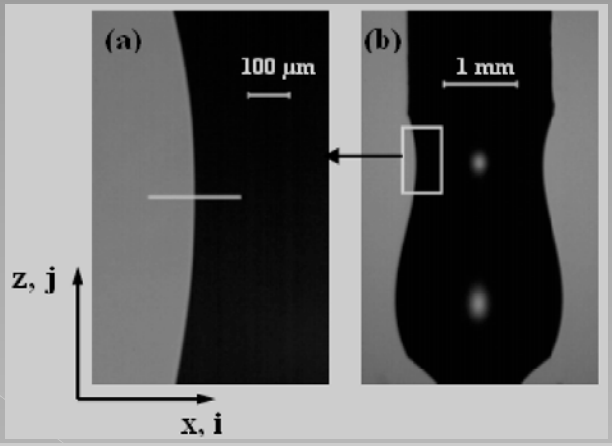
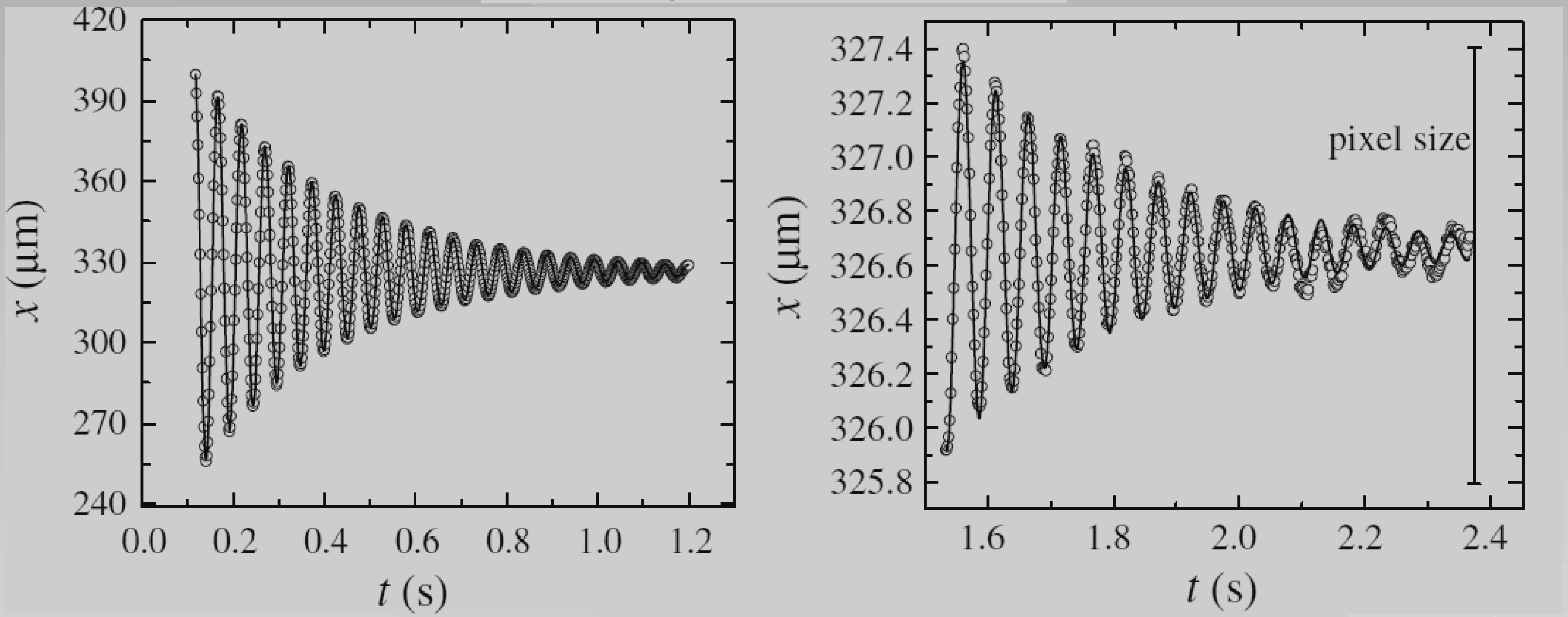


Image processing technique





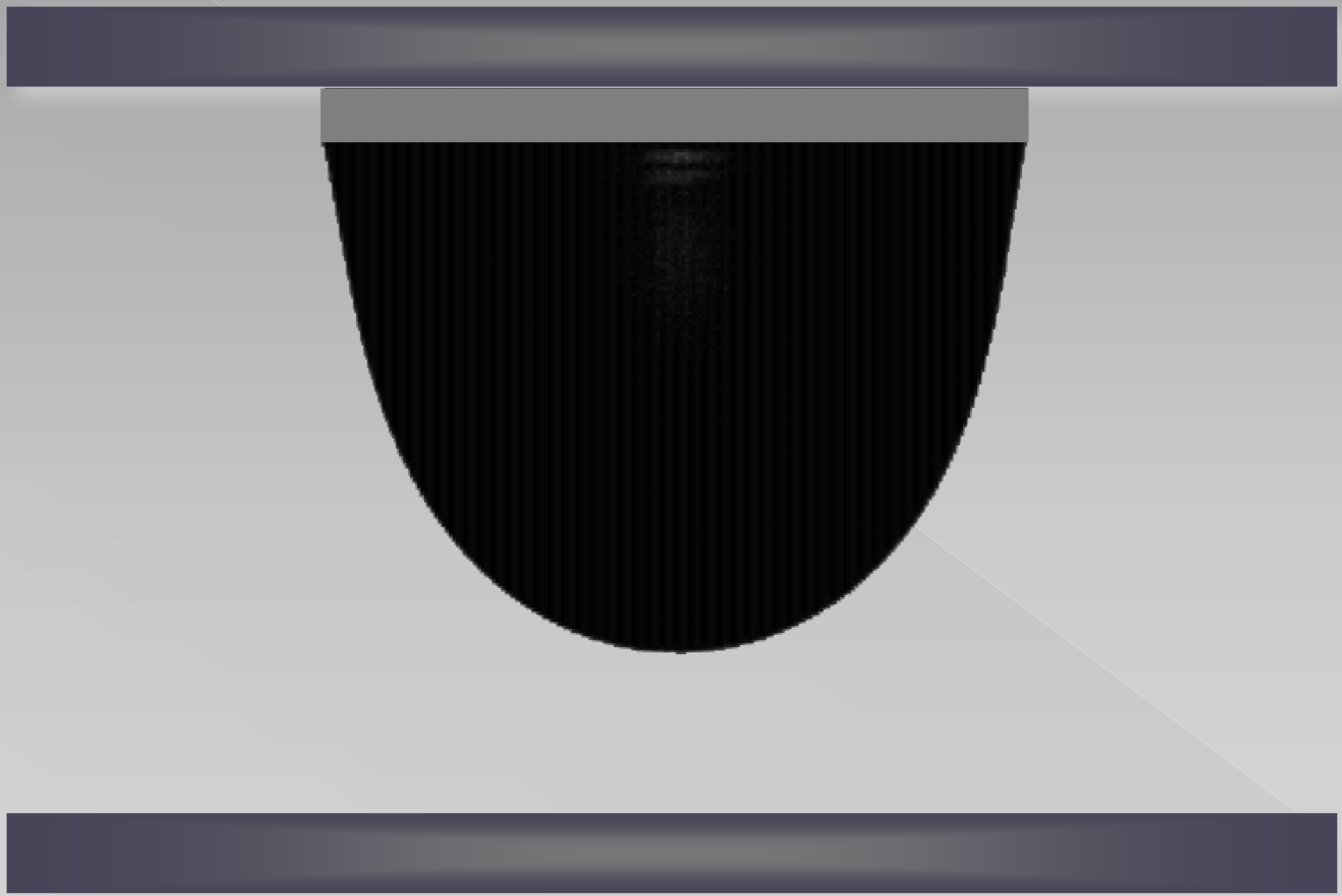
$$x = x_0 + A\exp^{-\alpha t}\cos(\omega t + \varphi)$$

100 μm ⇒ 100 nm

Electrified pendant drops

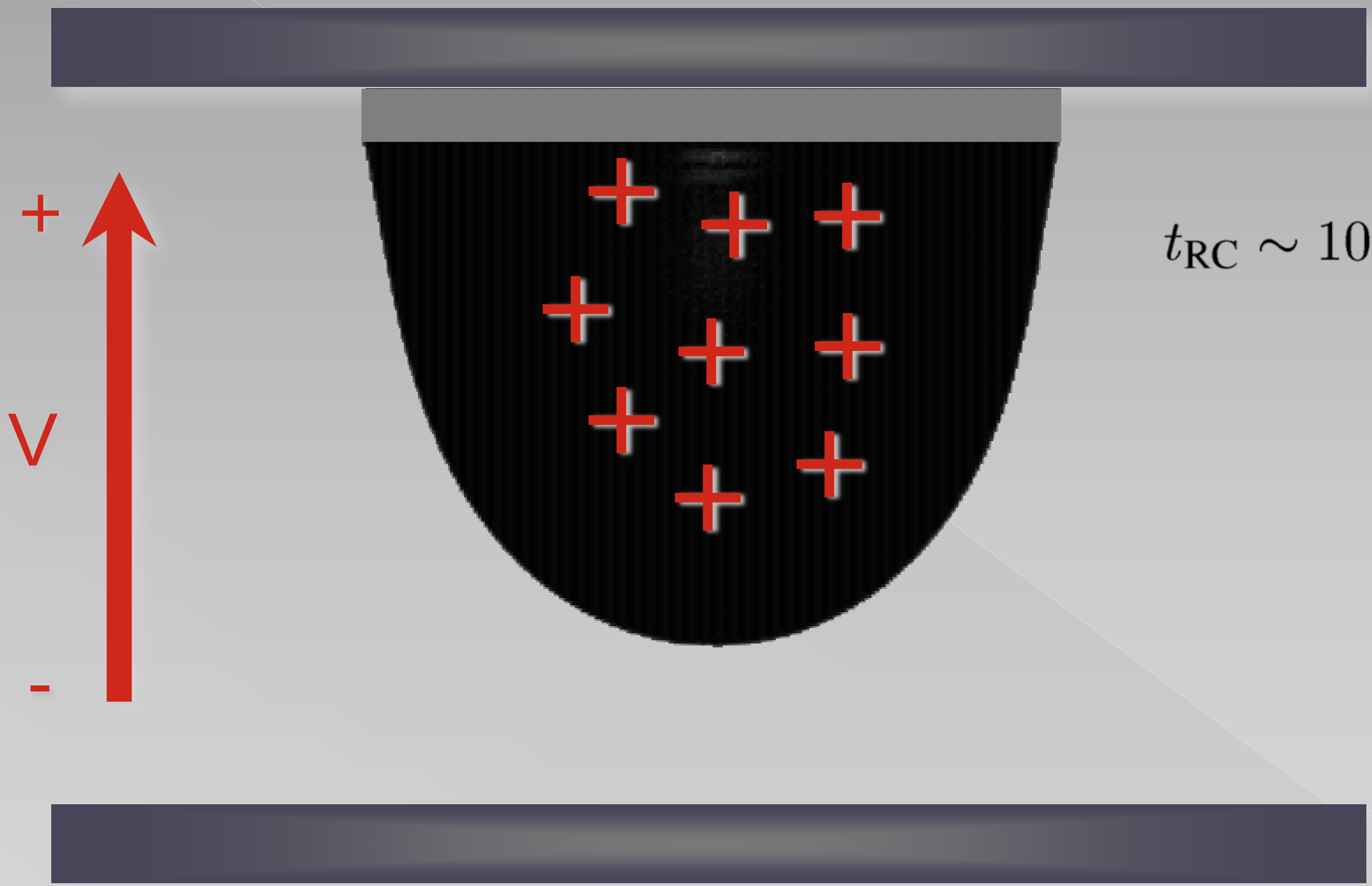
Low-conductivity pendant drop

$$K = 9 \times 10^{-7}\ \mathrm{S/m}$$



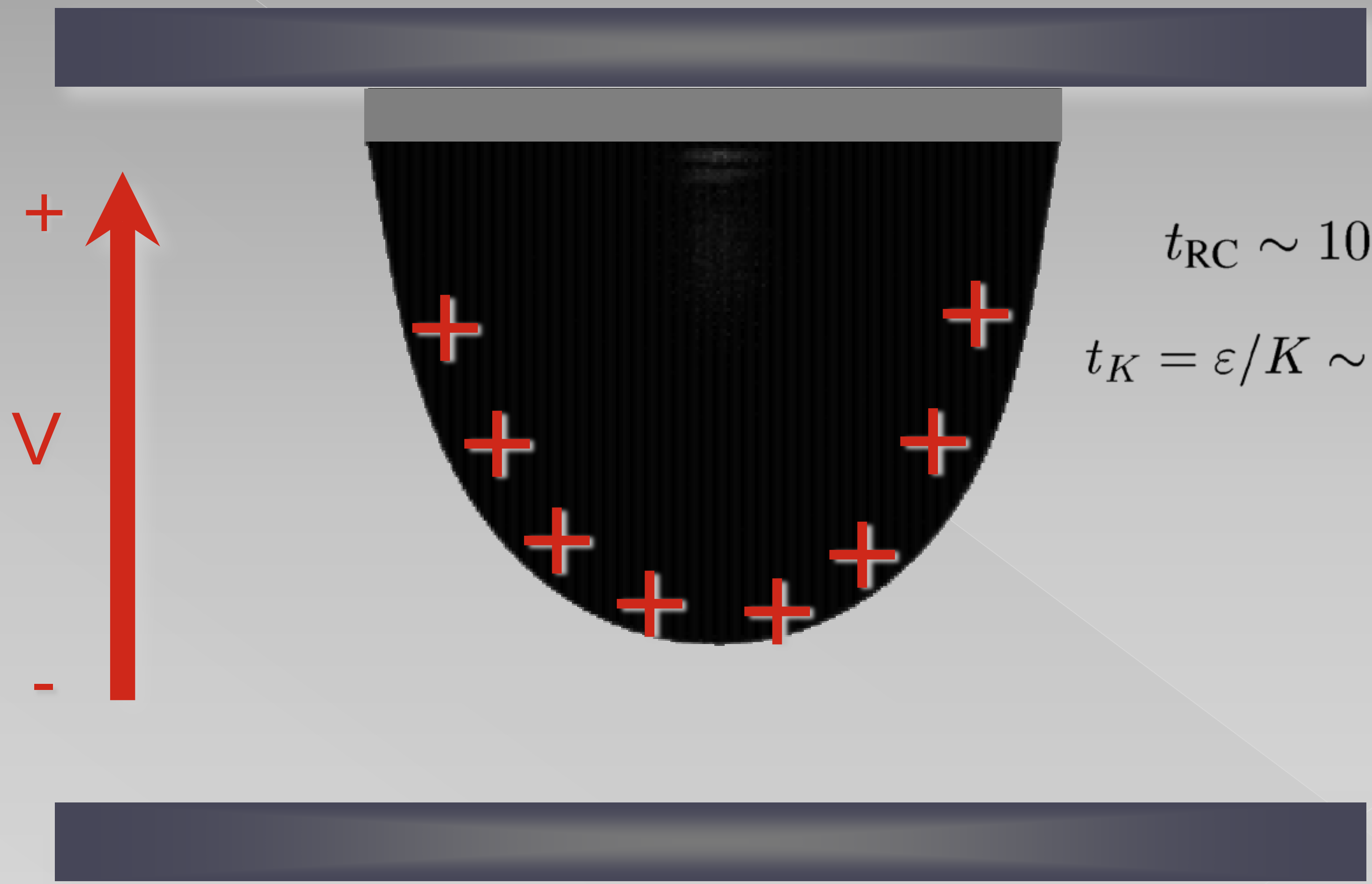
Electrified pendant drops

V 2-3 kV



$t_{\mathrm{RC}} \sim 10^{-7}$ s

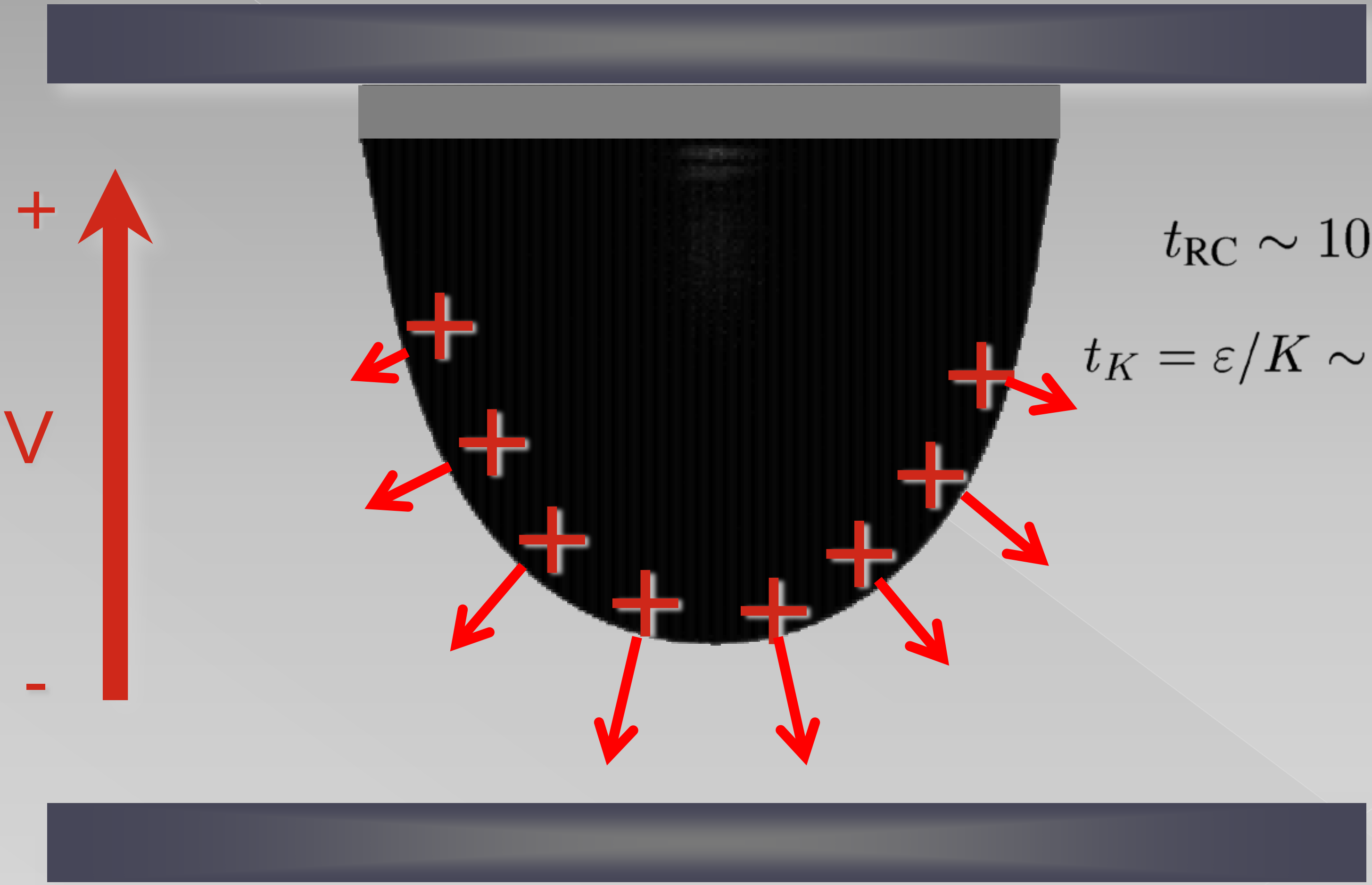
Electrified pendant drops



$$t_{\mathrm{RC}} \sim 10^{-7}\ \mathrm{s}$$

$$t_K = \varepsilon / K \sim 10^{-4}\ \mathrm{s}$$

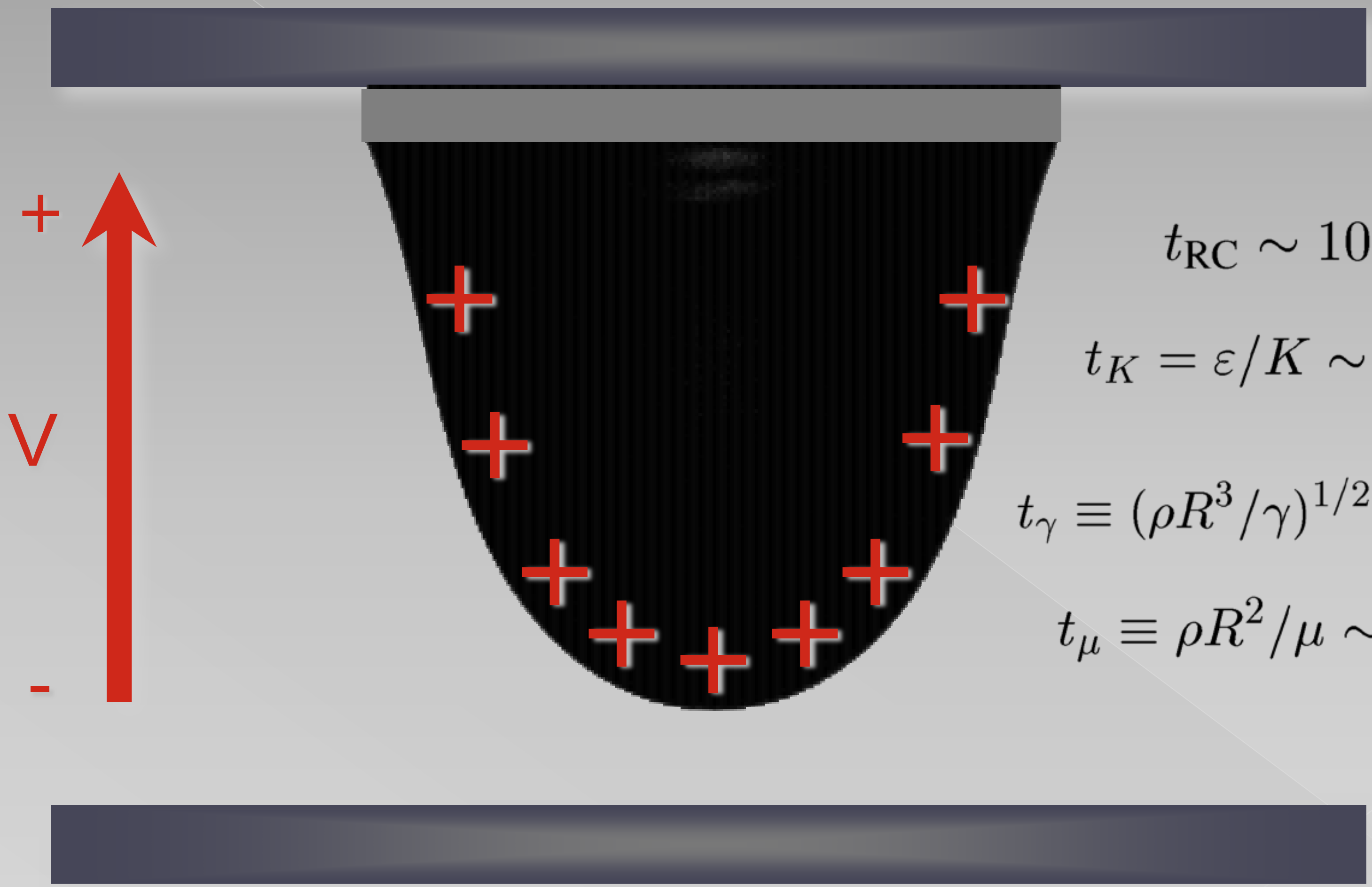
Electrified pendant drops



$$t_{\rm RC} \sim 10^{-7}\ {\rm s}$$

$$t_K = \varepsilon / K \sim 10^{-4}\ {\rm s}$$

Electrified pendant drops



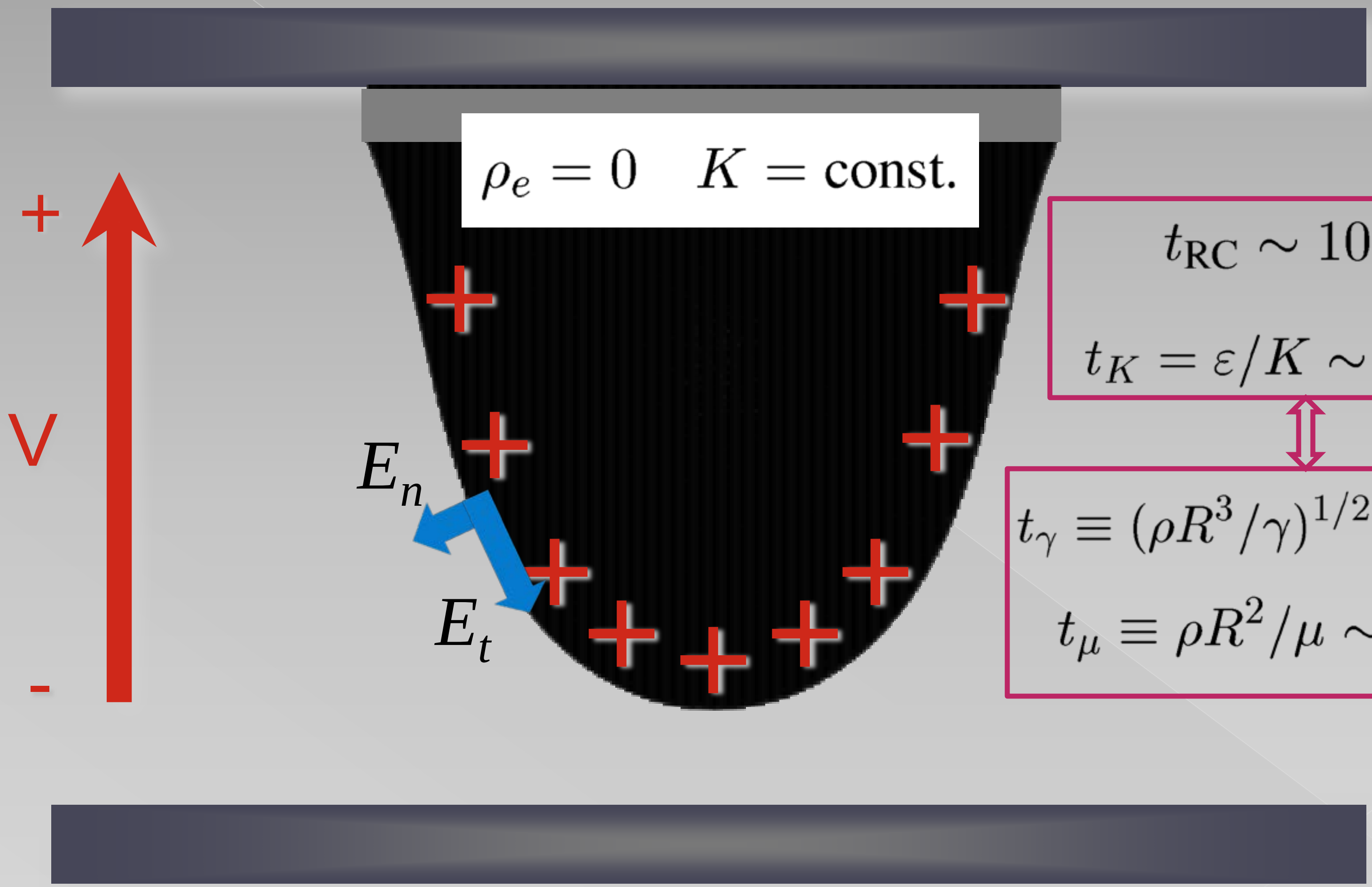
$$t_{\mathrm{RC}} \sim 10^{-7}\ \mathrm{s}$$

$$t_K = \varepsilon/K \sim 10^{-4}\ \mathrm{s}$$

$$t_\gamma \equiv (\rho R^3/\gamma)^{1/2} \sim 10^{-2}\ \mathrm{s}$$

$$t_\mu \equiv \rho R^2/\mu \sim 10^{-1}\ \mathrm{s}$$

The leaky-dielectric model



$$t_{\mathrm{RC}} \sim 10^{-7}\ \mathrm{s}$$

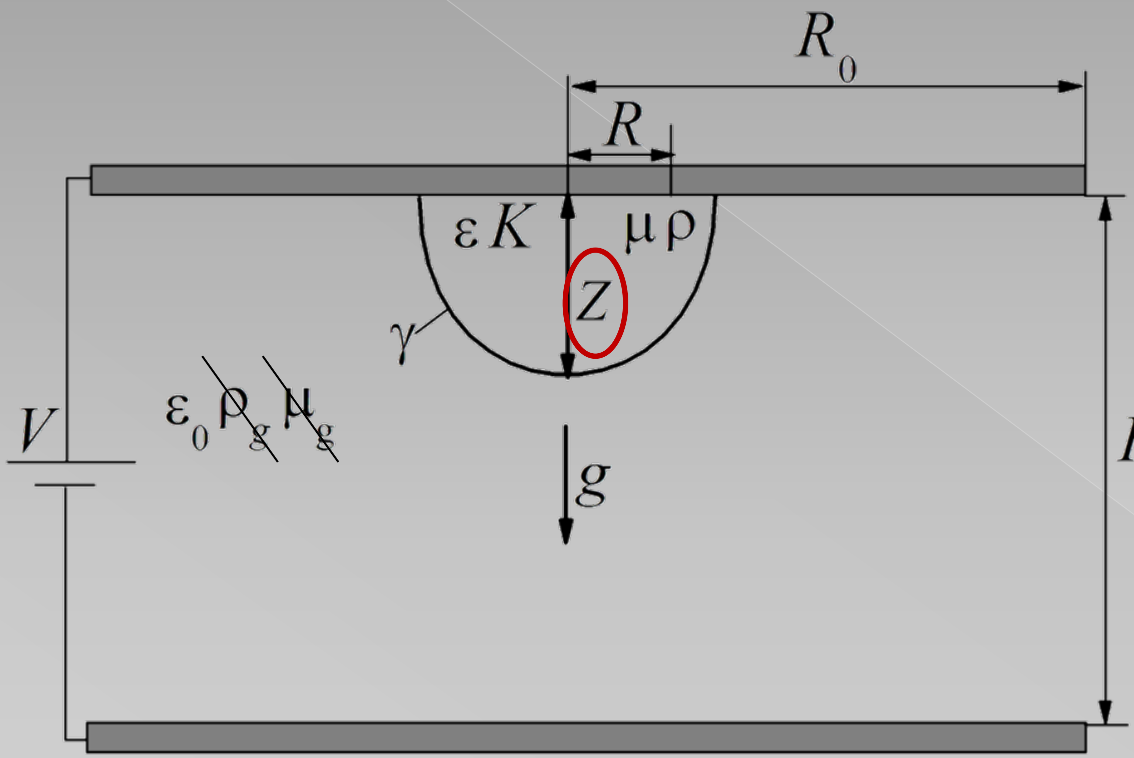
$$t_K = \varepsilon / K \sim 10^{-4}\ \mathrm{s}$$

$\Updownarrow$

$$t_\gamma \equiv (\rho R^3/\gamma)^{1/2} \sim 10^{-2}\ \mathrm{s}$$

$$t_\mu \equiv \rho R^2/\mu \sim 10^{-1}\ \mathrm{s}$$

Formulation of the problem



$$\hat{\mathcal{V}} = \mathcal{V}/R^3$$

$$C = \mu(\rho\gamma R)^{-1/2}$$

$$B = (\rho - \rho_g) g R^2/\gamma$$

$$\hat{K} = \left[\rho R^3 K^2/(\gamma \varepsilon_0^2)\right]^{1/2}$$

$$\varepsilon_r = \varepsilon/\varepsilon_0$$

$$B_e = \varepsilon_0 V^2/(R\gamma)$$

Subcritical drops

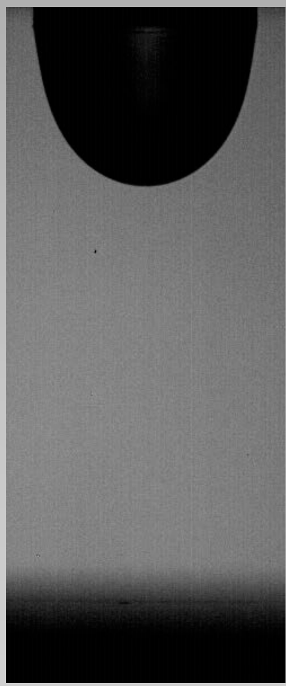
$$B_e < B_{ec}(\hat{V}, C, B, \hat{K}, \varepsilon)$$

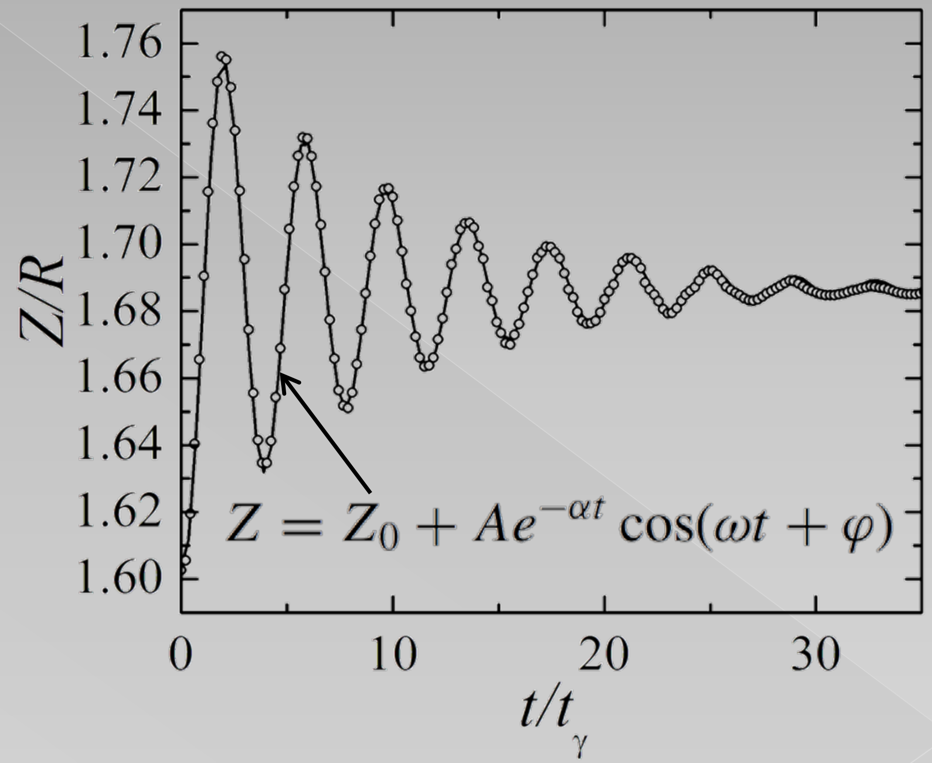
Capillary time

$$t_\gamma \equiv (\rho R^3/\gamma)^{1/2}$$

Viscous time

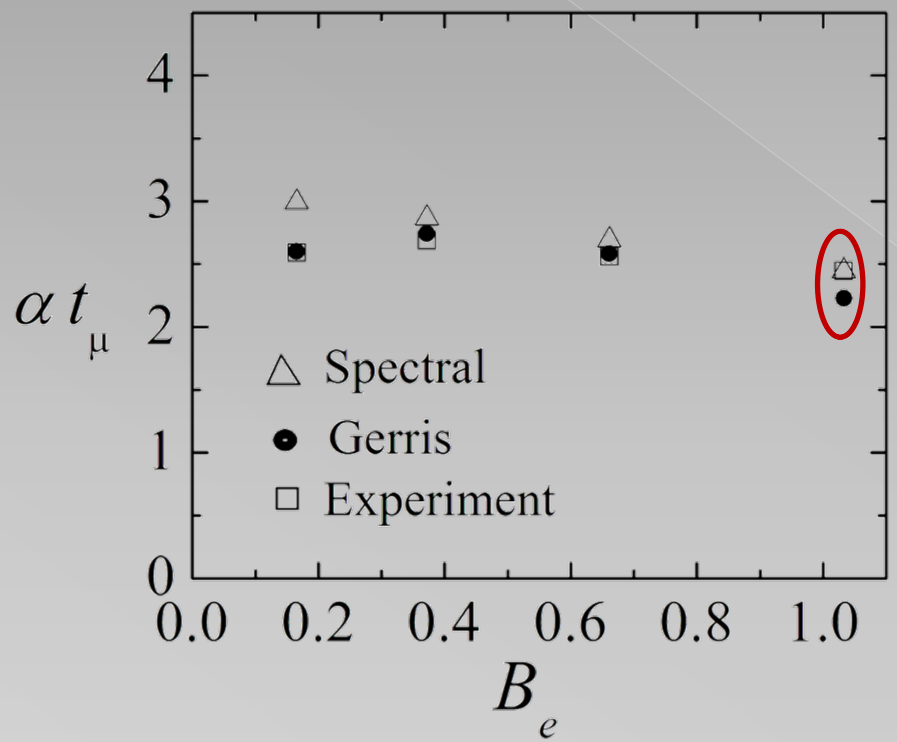
$$t_\mu \equiv \rho R^2/\mu$$

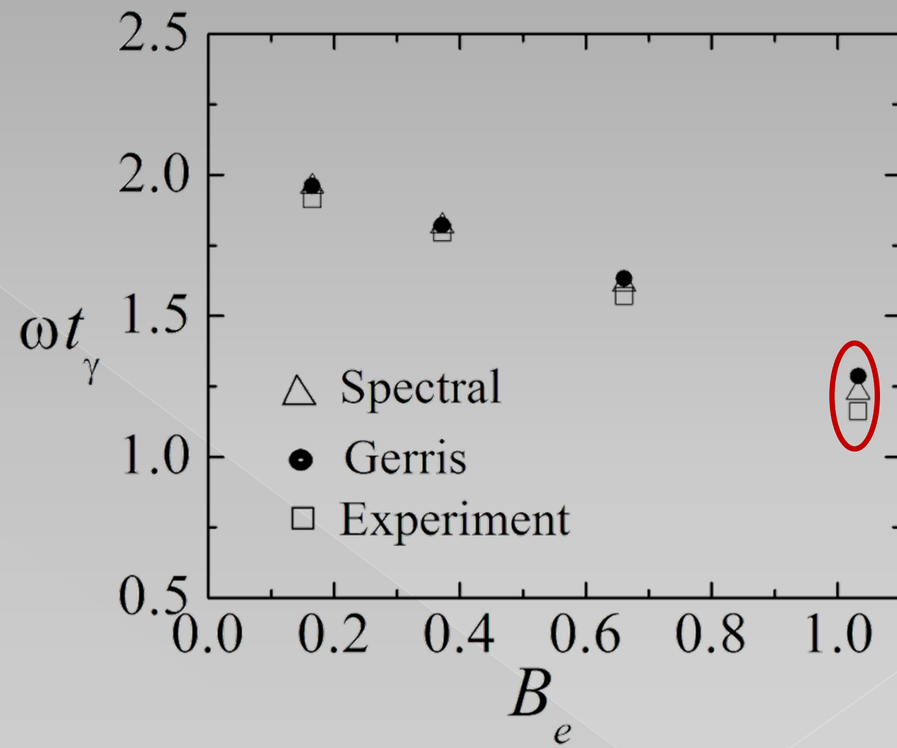




Subcritical drops

$$Z = Z_0 + Ae^{-\alpha t}\cos(\omega t + \varphi)$$

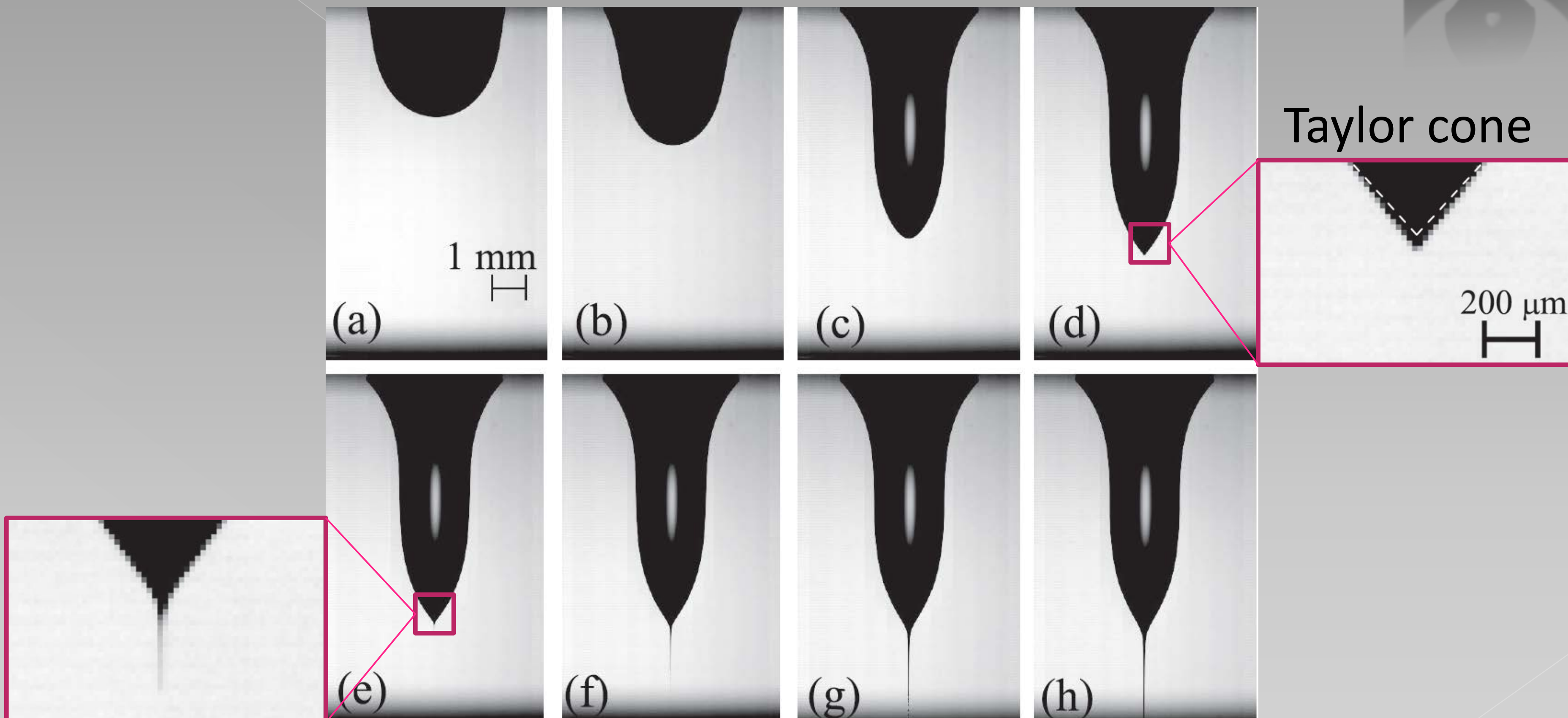




Gerris

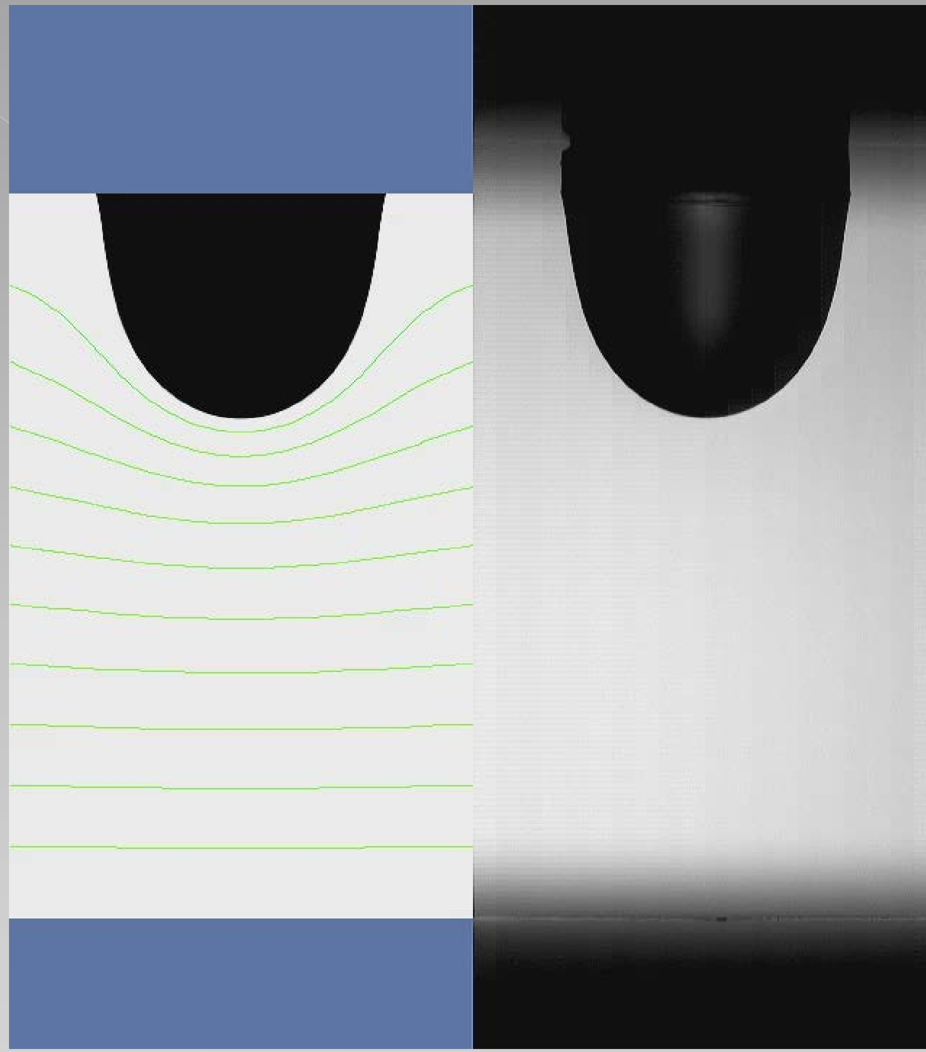
Supercritical drops

$$B_e > B_{ec}(\hat{V}, C, B, \hat{K}, \varepsilon)$$



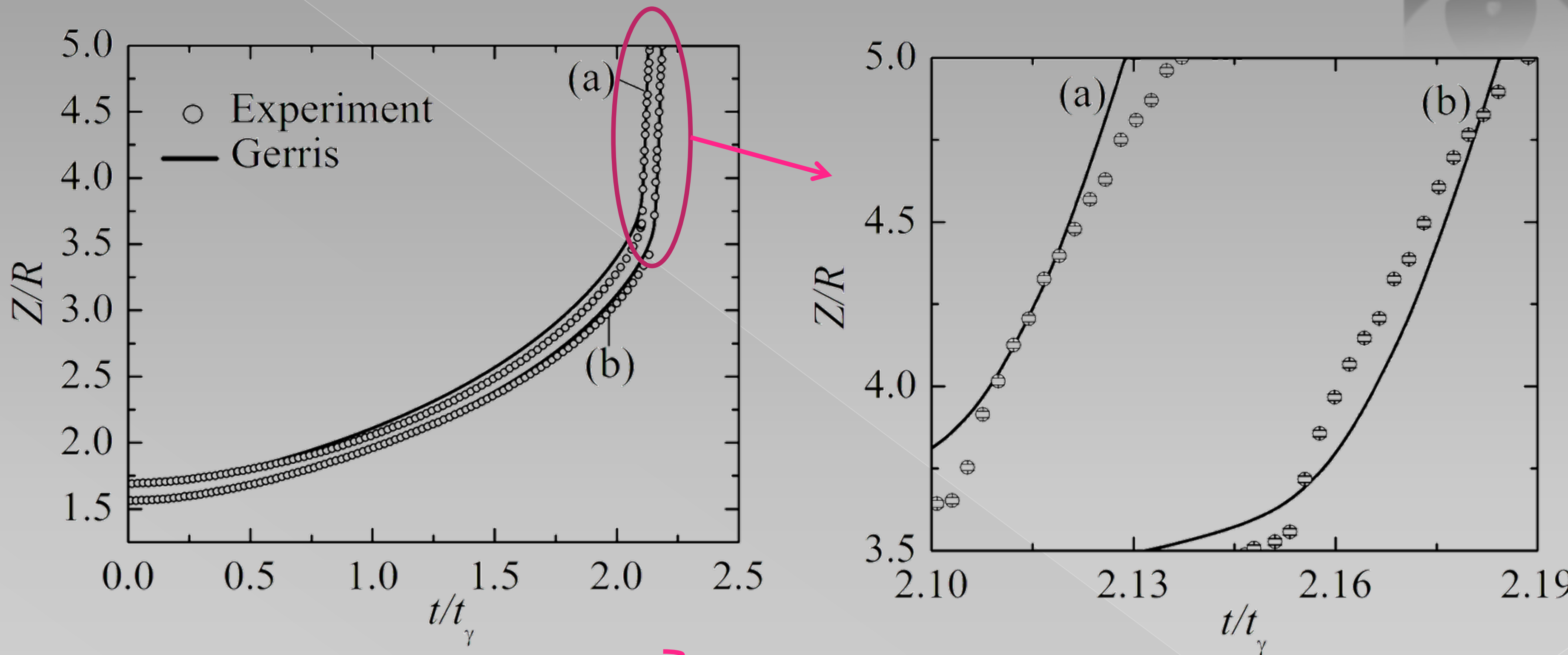
Supercritical drops

Gerris   Experiment



$\Delta t \approx 10^{-2}$ s

Supercritical drops



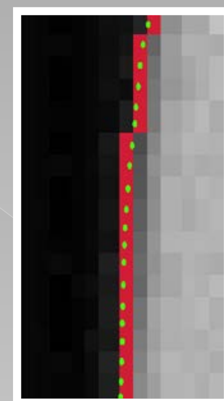
$$t_K = \varepsilon/K \sim 10^{-4}\ \mathrm{s}$$

$$t_\gamma^* \equiv (\rho R_j^3/\gamma)^{1/2} \simeq 1.6 \times 10^{-5}\ \mathrm{s}$$

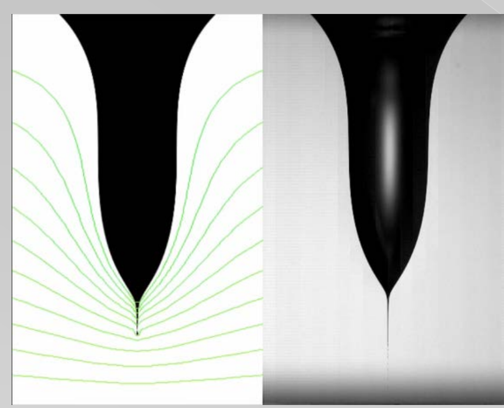
Charge relaxation effects!

Conclusions

✓ We have described an experimental method to measure the free surface position with high spatial and temporal resolutions



✓ We have compared Gerris and experimental results for electrified drops



Gerris


Dank U
mahalo
Köszi
obrigado
Merci
Takk
mauruuru
Grazie
Thank you
спасибо
Kiitos
danke
Gracias
Dziękuję
Děkuju