Thickness measurements of a soap film through fluorescent light emission and application to internal waves visualisation

August Burg

Erasmus: Master Ondes, Atomes et Matière, Université Côte d'Azur,
B.Sc. Physik, WWU Münster

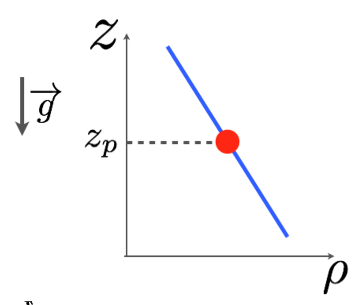
Supervisors: Christophe Brouzet, Christophe Raufaste, Franck Celestini

Institut de Physique de Nice

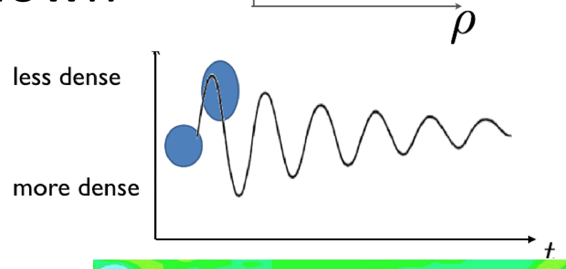
Abstract: Vertical soap films have vertical thickness profiles that can be exploited to generate internal waves in analogy with density stratified fluids. To reach this goal, it is important to have a precise measurement of the local thickness everywhere in the film. I propose a method based on the emission of fluorescent light in the soap film. I present the experimental setup to perform the calibration between the intensity *I* of fluorescent light emission and the thickness *e* of the soap film and validate the calibration theoretically.

What is an internal wave?

- density stratified fluid: ρ decreases with the height *z*



- when a fluid particle gets pushed up or down
  - ➡ Archimedes principle as restoring force
  - ➡ oscillations: waves can propagate



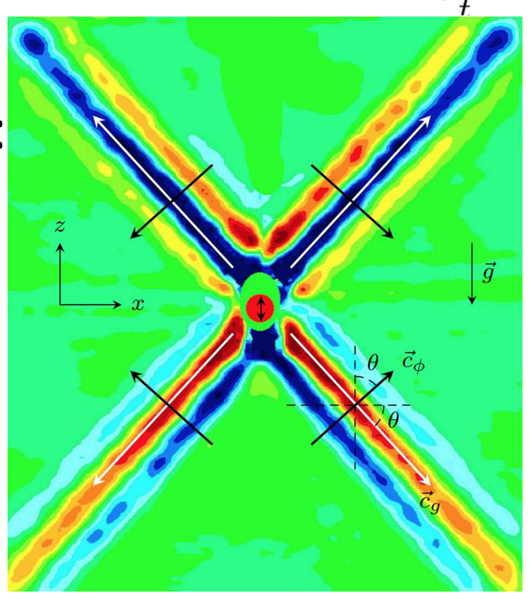
- charateristic pulsation of the stratified fluid: the Brunt-Väisälä-pulsation N

$$N = \sqrt{-\frac{g}{\rho}\frac{\mathrm{d}\rho}{\mathrm{d}z}}$$

- dispersion relation: $\frac{\omega}{N} = \pm \sin\theta$

θ: angle of propagation, ω: perturbating pulsation

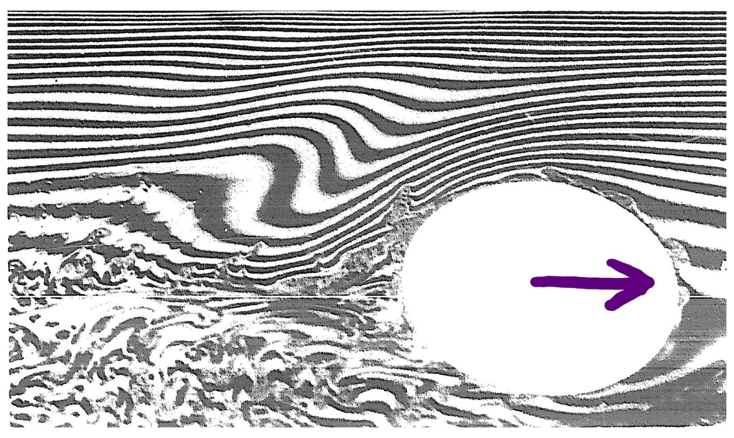
- group velocity orthogonal to phase velocity



Internal waves propagating in a stratified fluid created by vertical oscillating cylinder [1]

Are there internal waves in a soap film?

- the thickness *e* of a vertical soap film decreases with the height
  - ➡ analogy to a stratified fluid
- first experiment by Couder *et al*. [2]: perturbating the film by toeing an aluminum disk



Soap film around a moving disk

Thickness measurement à la Fabry-Pérot

interference of the reflected light [3]

$$\epsilon_{max} = \frac{(2k-1)\lambda}{4n_2\cos(\theta_2)}$$

$$\epsilon_{min} = \frac{k\lambda}{2n_2\cos(\theta_2)}$$

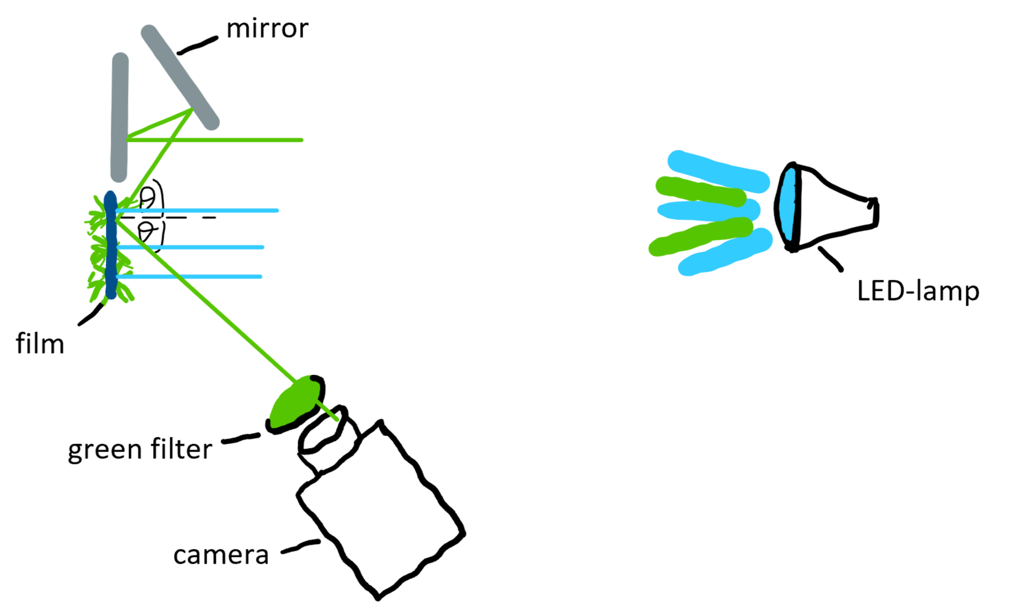
-no study of the propagation

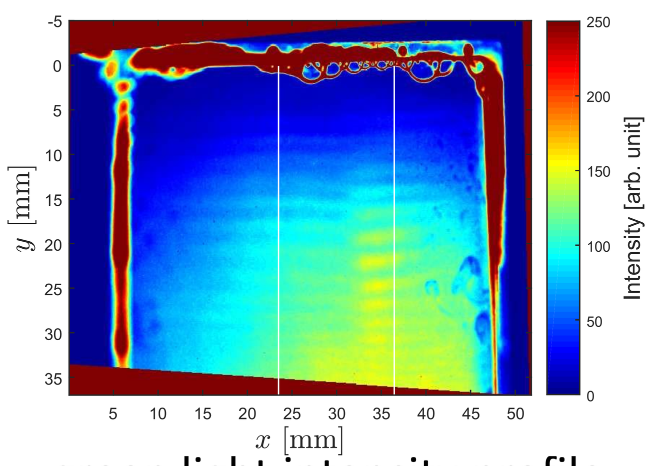
- **new** experiment: a vertical oscillation cylinder in the soap film

-a more sensitive measurement of thickness variations is needed:

➡ **light emitted by fluorescein dissolved in the soap film**

Experimental setup to calibrate the fluorescent light emission





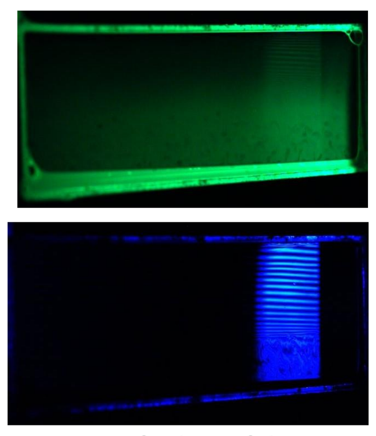
green light intensity profile

- 2 different regions on the film

-left: fluorescent light only

-right: the soap film reflects the LED-light

➡ thickness measurement à la Fabry-Pérot



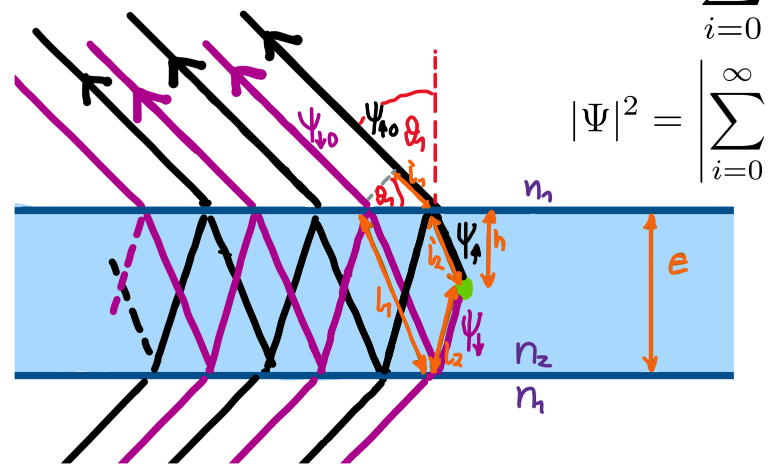
pictures of the film with a green and a blue filter

Derivation of a formula for the fluorescent light intensity

wave function of the light emitted by one molecule:

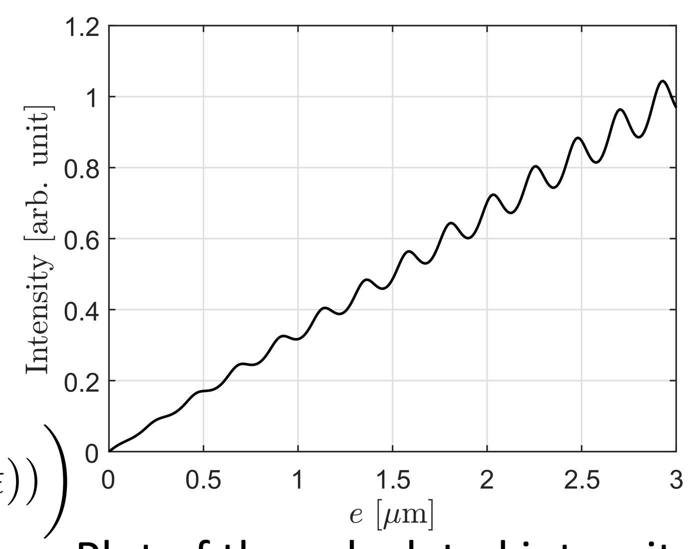
$$\Psi = \sum_{i=0}^{\infty}\Psi_{\uparrow i} + \sum_{j=0}^{\infty}\Psi_{\downarrow j}$$

$$|\Psi|^2 = \left|\sum_{i=0}^{\infty}\Psi_{\uparrow i}\right|^2 + \left|\sum_{j=0}^{\infty}\Psi_{\downarrow j}\right|^2 + \left[\left(\sum_{i=0}^{\infty}\Psi_{\uparrow i}^*\right)\cdot\left(\sum_{j=0}^{\infty}\Psi_{\downarrow j}\right) + cc.\right]$$



$$I = \int_0^{\epsilon} I'(h)\mathrm{d}h$$

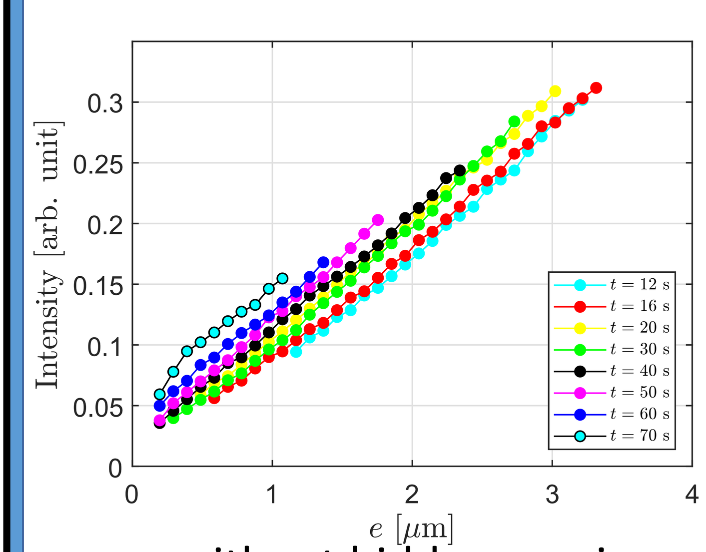
$$= \frac{I_0\cdot(t_{21})^2}{1 + r_{21}^4 - 2r_{21}^2\cos(b\epsilon)}\left(\epsilon(1 + r_{21}^2) + \frac{2r_{21}}{b}\sin(b\epsilon)\right)$$



Plot of the calculated intensity

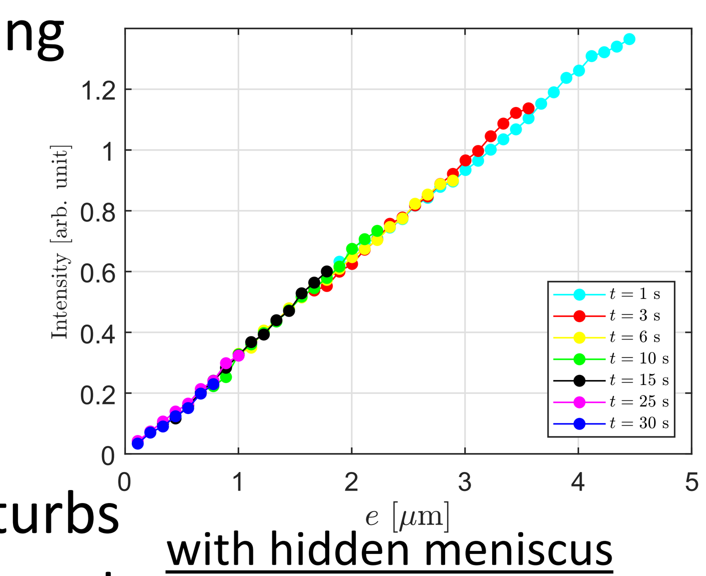
r_{21}: reflection coefficient, t_{21}: transmission coefficient, $b = 4\pi n_2\cos(\vartheta_2)/\lambda$

Performing the calibration: intensity vs. thickness



without hidden meniscus

- slight averaging over height
  - ➡ ***linear calibration***
- meniscus disturbs the measurement

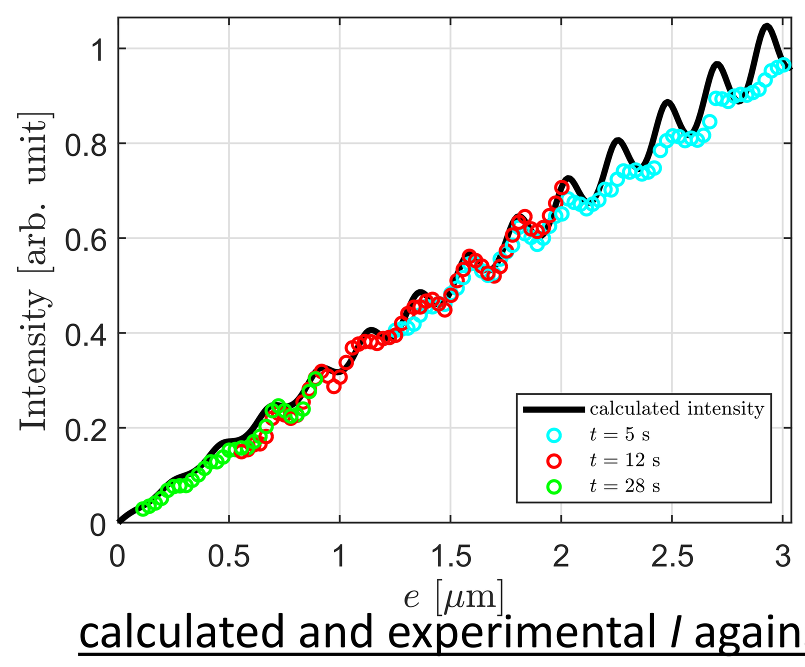


with hidden meniscus

Validation of the formula by the experiments

Results:

- experimental values match for $e < 2$ µm
- only for $e > 2$ µm the contrast is lower



calculated and experimental *I* against *e*

References

[1] C. Brouzet, PhD thesis Université de Lyon (2016), Internal wave attractors : from geometrical focusing to non-linear energy cascade and mixing

[2] Y. Couder, J.M. Chomaz and M. Rabaud, Physica D 37 (1989), On the hydrodynamics of soap films

[3] L. Atkin, R. Elliott, : American Journal of Physics 78 (2010), Investigating thin film interference with a digital camera