The bubble bursting acoustic signature

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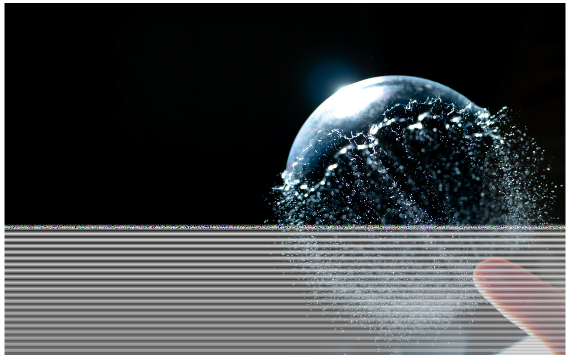
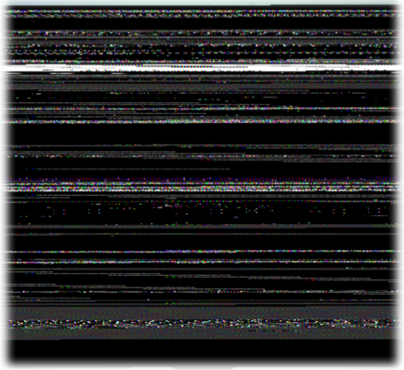
E. Blanc & V. Bertin





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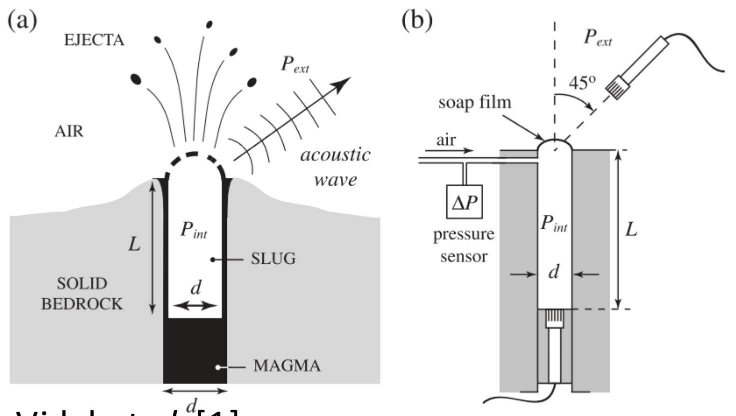
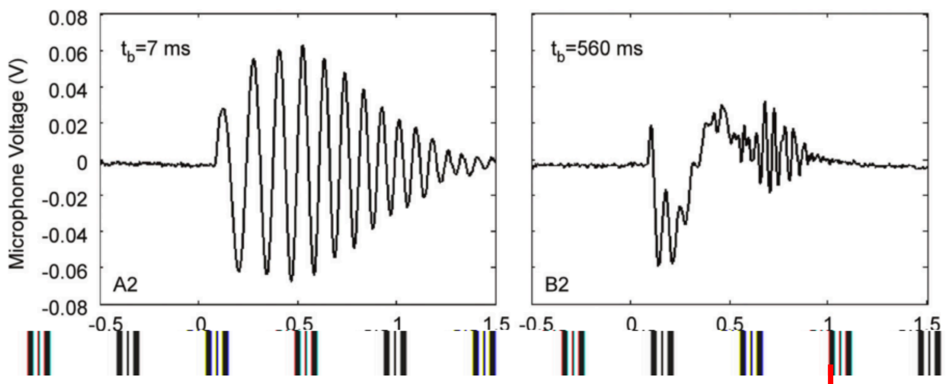
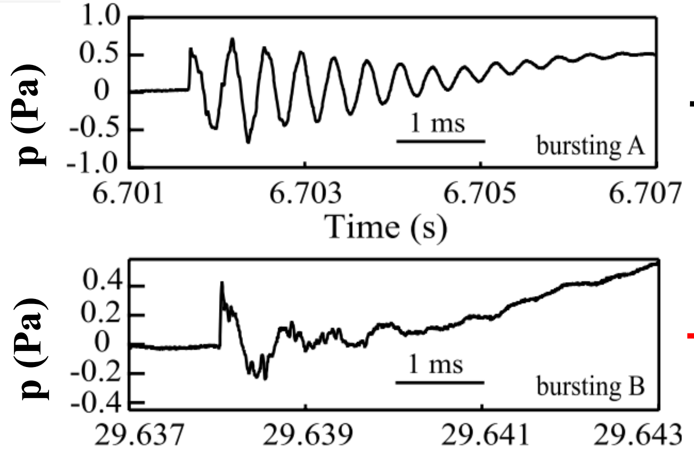
Introduction



Vidal *et al.* [1]

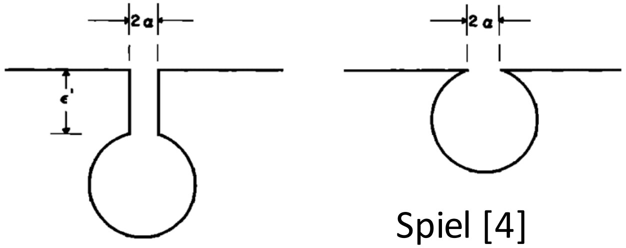


Deane [3]



Vidal *et al.* [2]

Helmholtz resonator



Spiel [4]

?

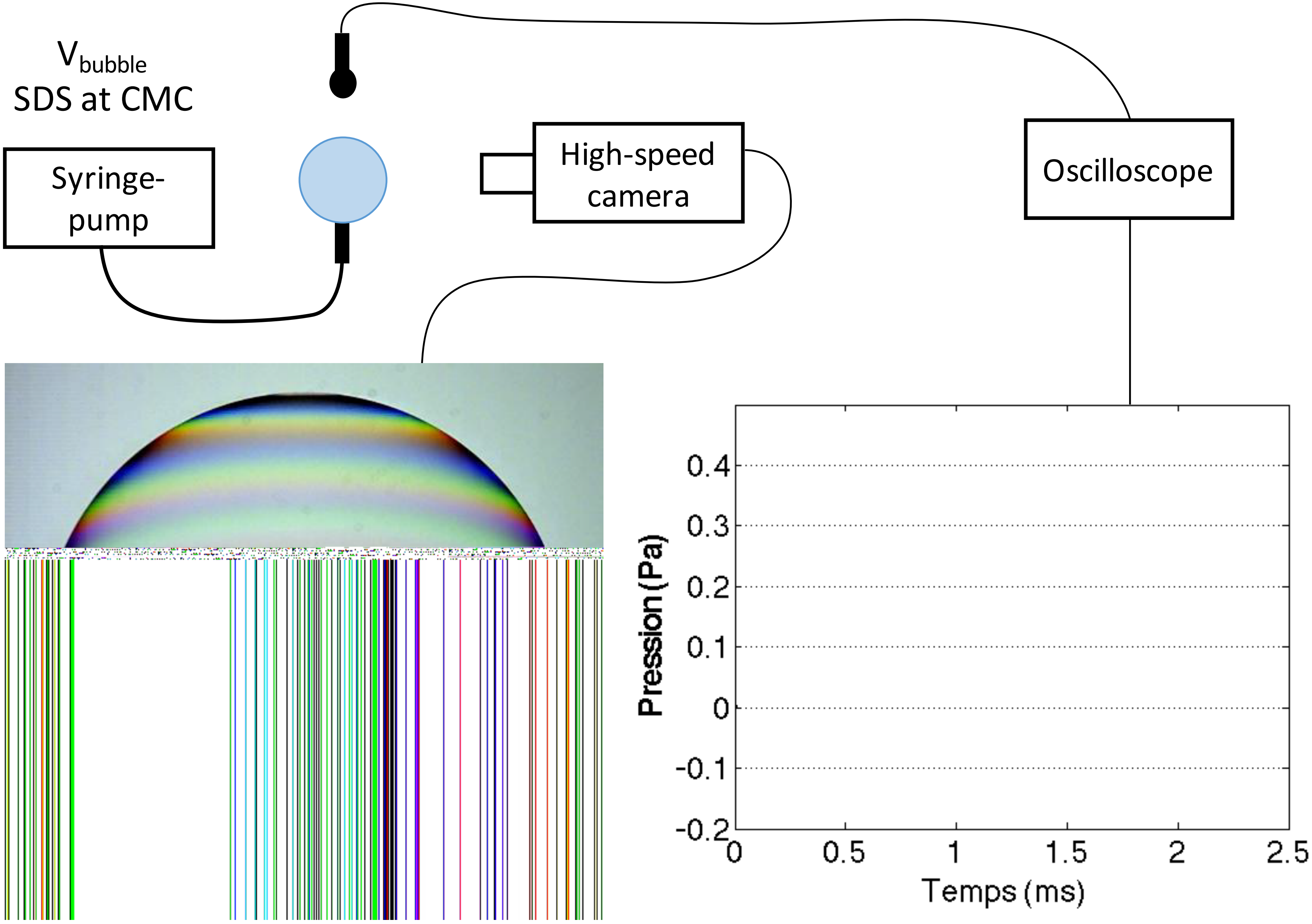
[1] V. Vidal *et al.,* Dynamics of soap bubble bursting and its implications to volcano acoustics, *Geophys. Res. Lett.*, 2010, 37

[2] V. Vidal *et al.,* Acoustic waveform of continuous bubbling in a non-Newtonian fluid, PRE, 2009, 80

[3] G. Deane, Determining the bubble cap film thickness of bursting bubbles from their acoustic emissions, JASA, 2013, 133

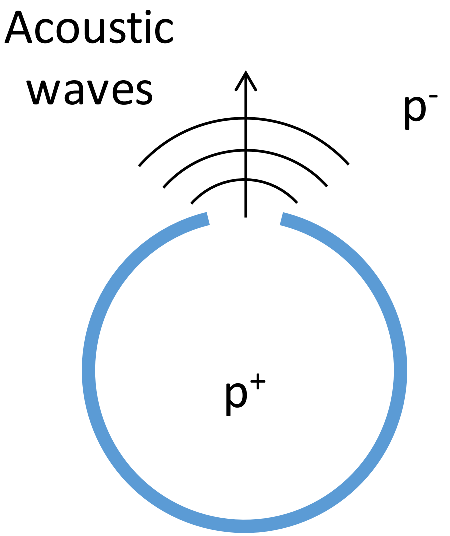
[4] D. Spiel, Acoustical Measurements of Air Bubbles Bursting at a Water Surface: Bursting Bubbles as Helmholtz Resonators, J. Geophys. Res., 1992, 97

Experimental setup



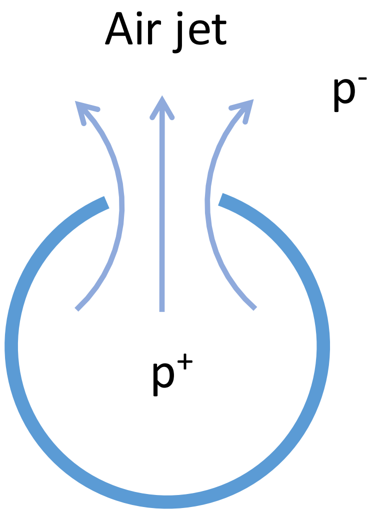
Characteristic timescales

Acoustic



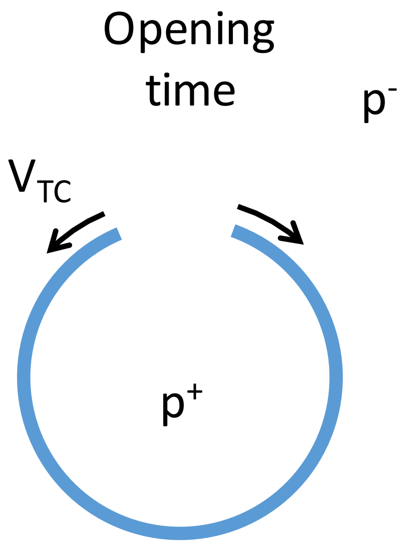
$$\xcancel{T_{ac} \sim \frac{R}{c} \sim 10\mu s}$$

Aeroacoustic



$$T_{jet} \sim \sqrt{\frac{\rho_g R^3}{4\sigma}} \sim 1ms$$

Hydrodynamic



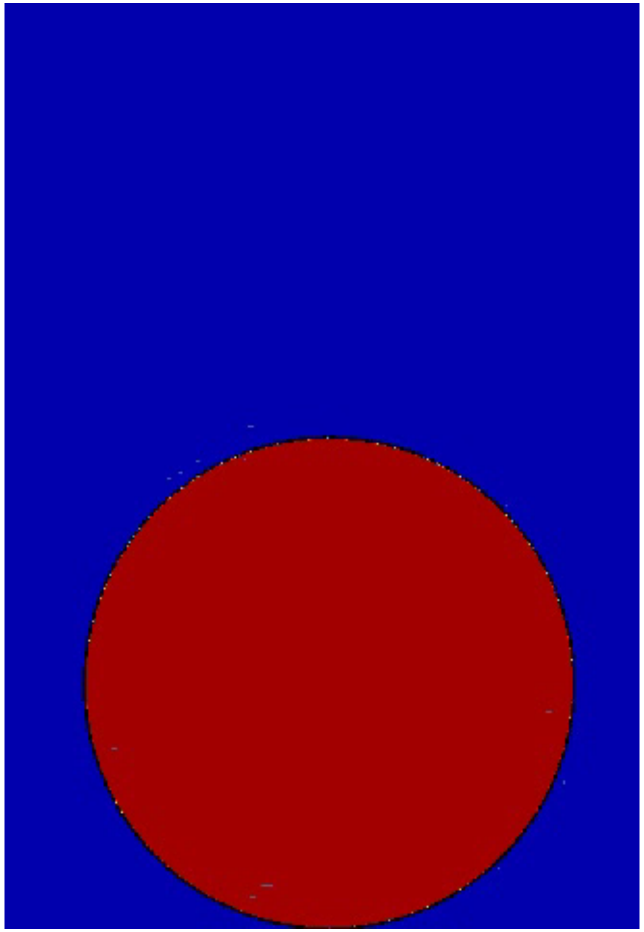
$$T_{film} \sim \frac{R}{v_{TC}} = R\sqrt{\frac{\rho_l e}{2\sigma}}$$

$$T_{film} \sim 1ms$$

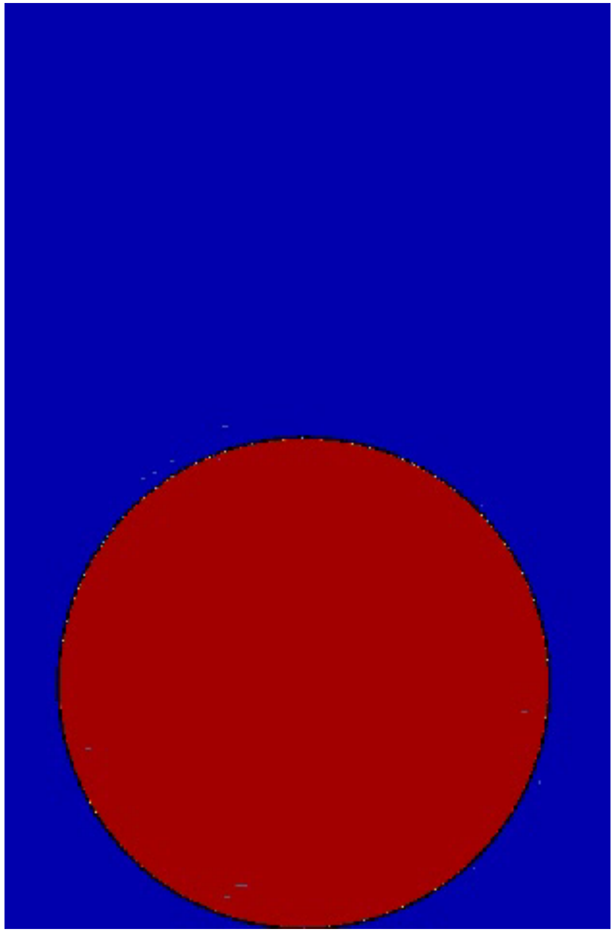
Characteristic timescales

$$\frac{T_{jet}}{T_{film}} \sim \sqrt{\frac{\rho_g}{\rho_l}\frac{R}{h}}$$

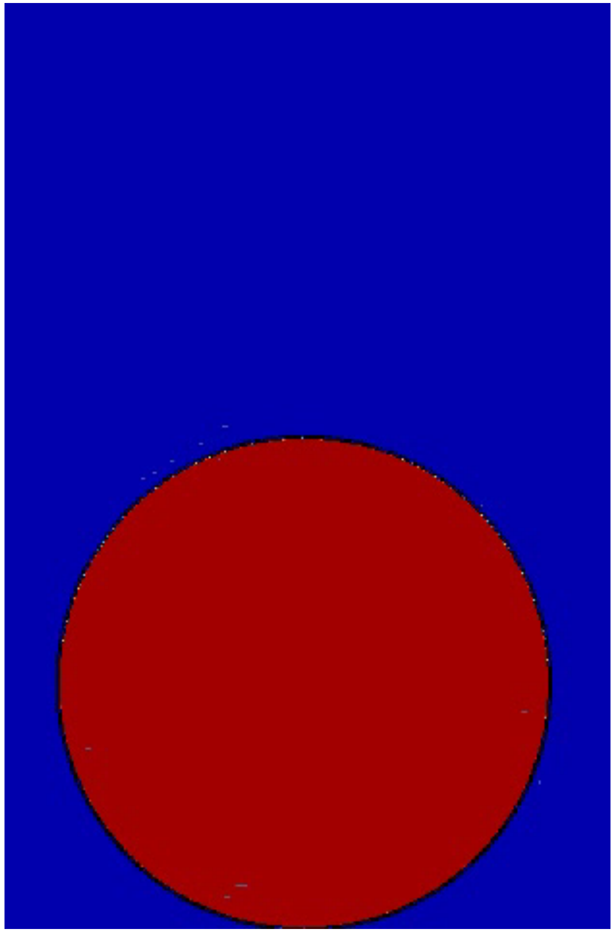
20



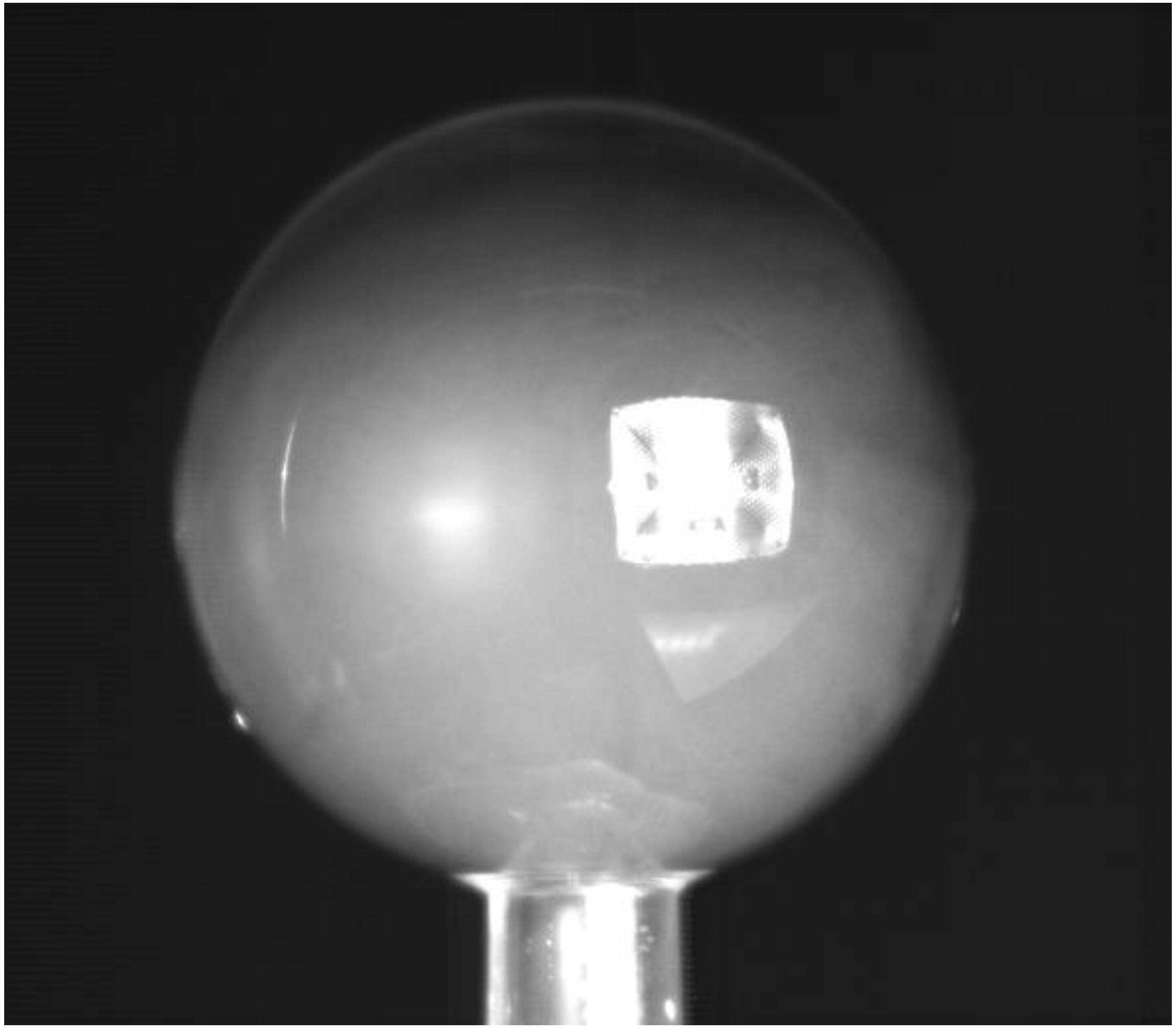
1



0,05



Characteristic timescales

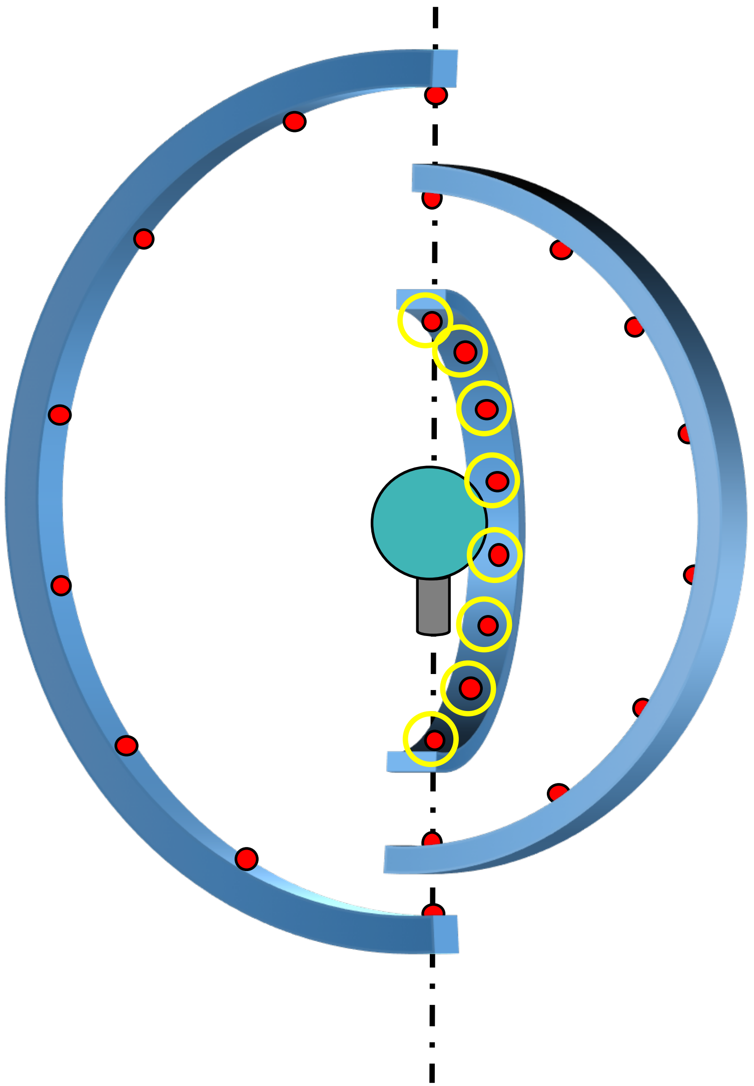


➡ **No air jet**

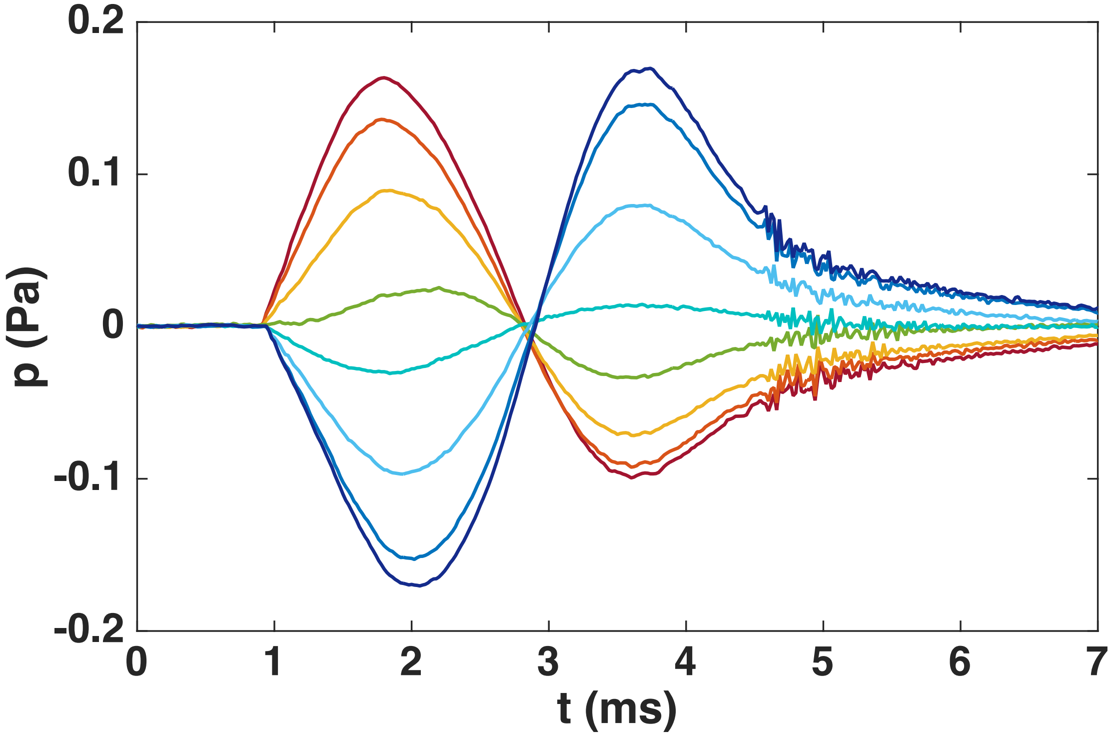
Opening time < Air jet time

Sound directivity

Microphone array



Axisymmetric hypothesis

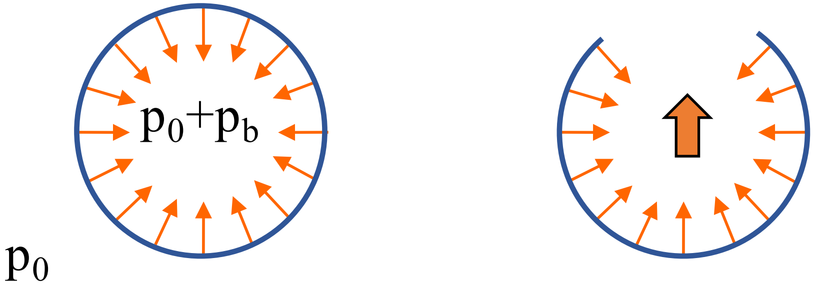


Dipole source

Simple model

- ✓ Dipole source ➾ **Force applied to the air**
- ✓ Signal period ≈ Opening time

➡ **Force applied by the liquid to the air during the bursting**


Initial state

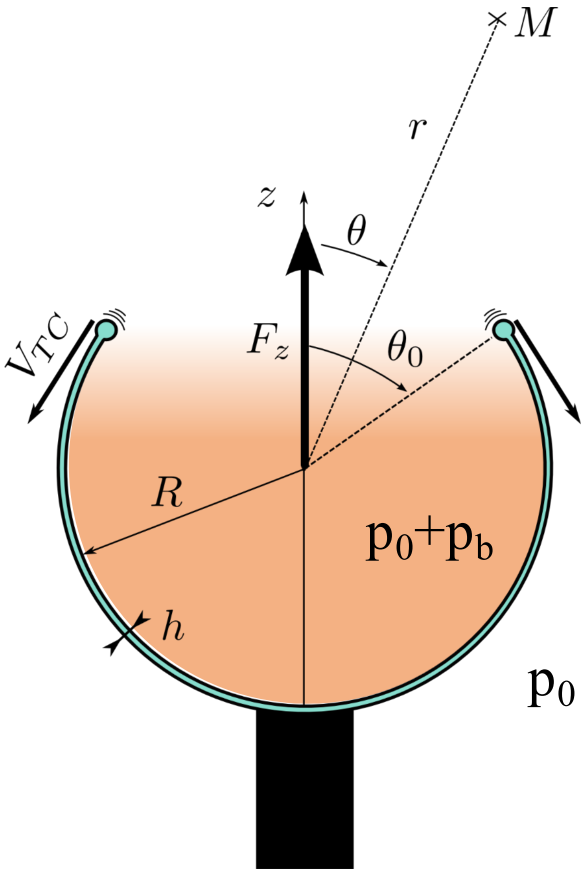
During the bursting

$$p_b = \frac{4\gamma}{R}$$

$$\theta_0(t) = \frac{V_{TC}}{R}t$$

$$F_z(t) = 2\pi R^2 \int_{\pi-\theta_0(t)}^{\pi} \frac{4\gamma}{R}\sin\theta\cos\theta\, d\theta$$

➡ $$F_z(t) = 4\pi\gamma R \sin\left(\frac{v_{TC}}{R}t\right)^2$$



Simple model

Radiation of the force source

$$\Delta p(\vec{r},t) - \frac{1}{c^2}p(\vec{r},t) = F_z(t)\vec{e}_z\vec{\nabla}.\delta(\vec{r})$$

$$p(\vec{r},t) = \frac{\cos\theta}{4\pi c r}\left(\boxed{\frac{dF_z}{dt}} + \boxed{\frac{c}{r}F_z}\right)$$

Far field

Near field

$$\Rightarrow \quad p(\vec{r},t) = \frac{\gamma}{cr}\cos\theta\left[\boxed{V_{TC}\sin\left(2\frac{V_{TC}}{R}\tau\right)} + \boxed{\frac{cR}{r}\sin^2\left(\frac{V_{TC}}{R}\tau\right)}\right]$$

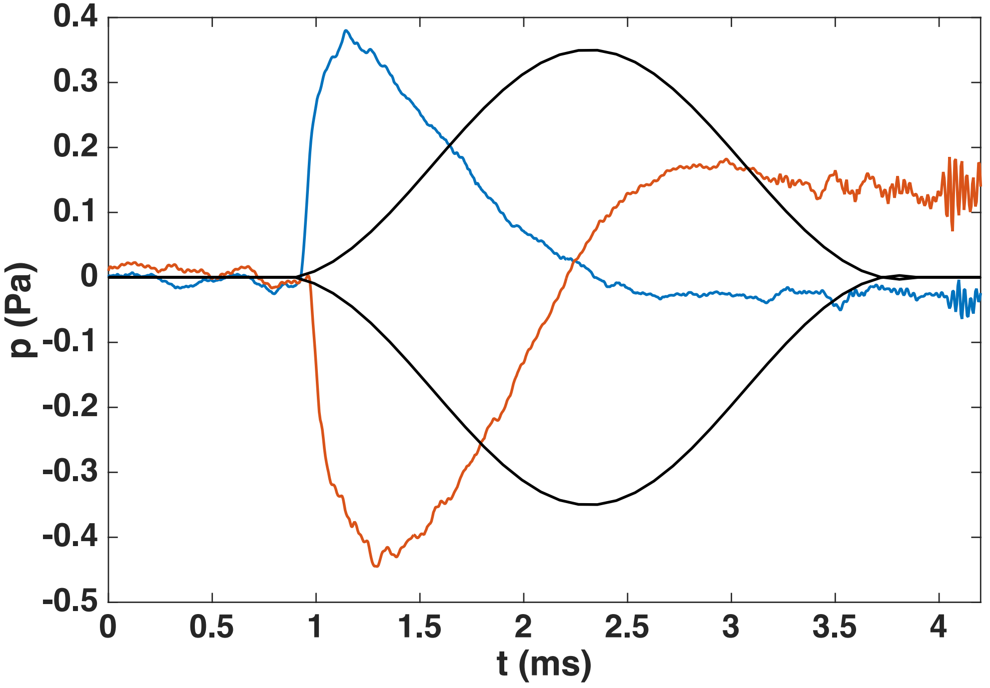
$$\tau = t - \frac{r}{c}$$

$$V_{TC} = \sqrt{\frac{2\gamma}{\rho_l h}}$$

V = 2mL

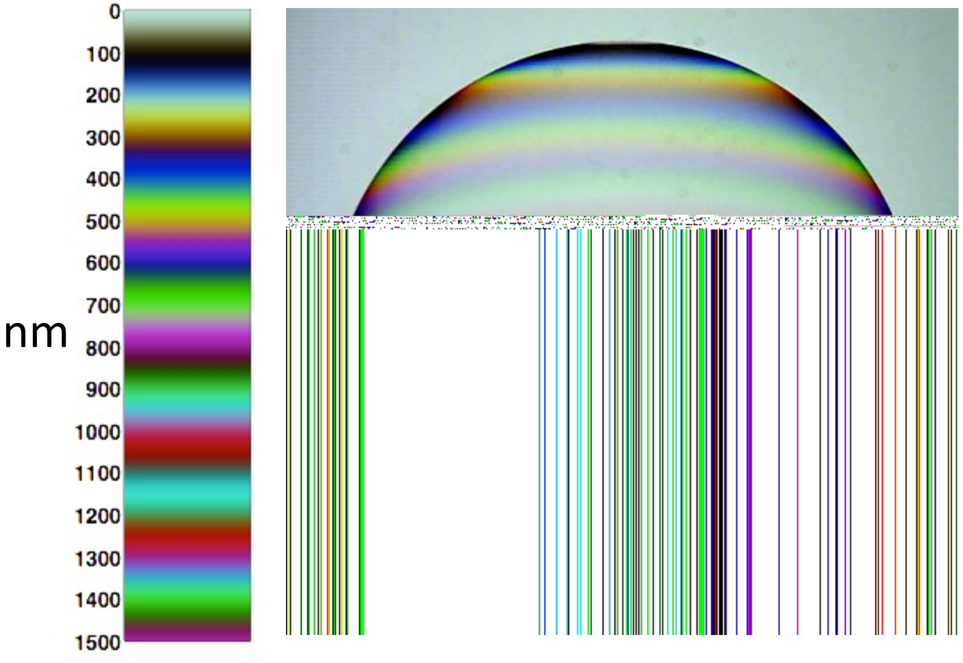
r = 30 mm

V_{TC} = Cste

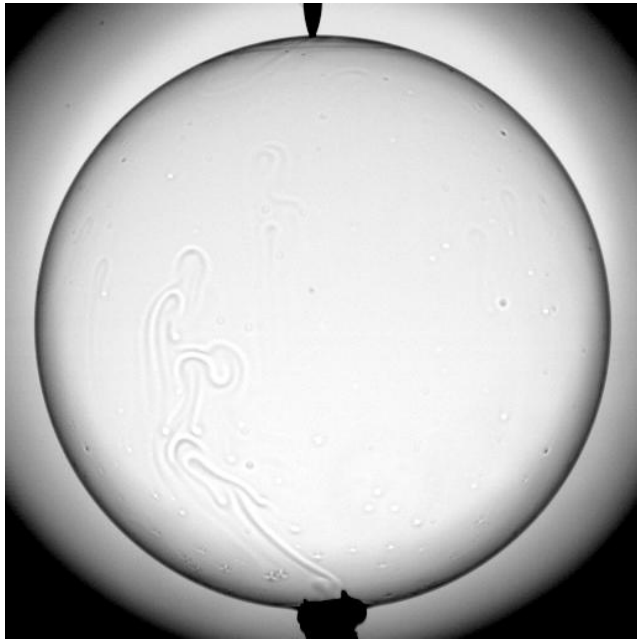


- Agreement on the amplitude
- Waveform in disagreement

Film thickness

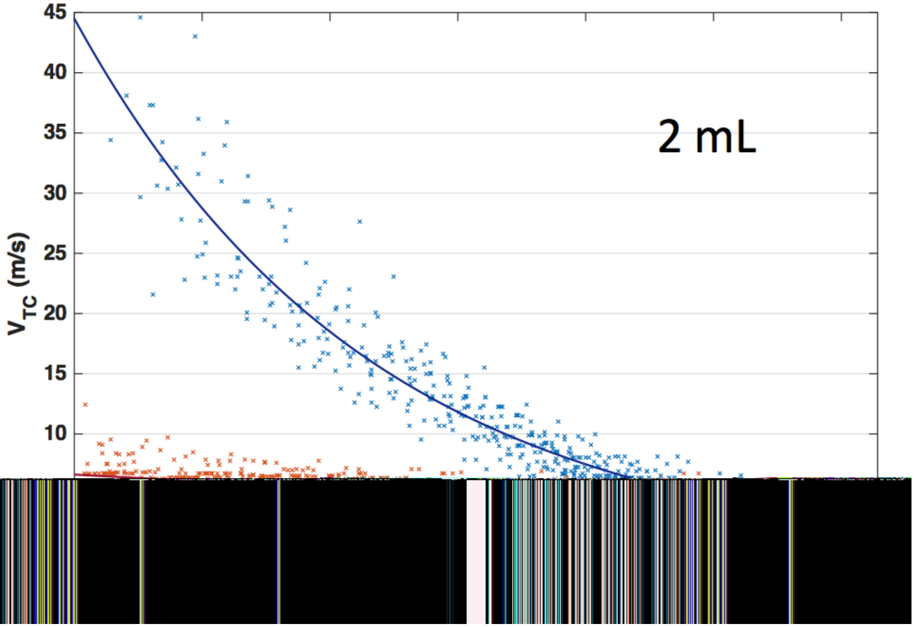


Forced bursting



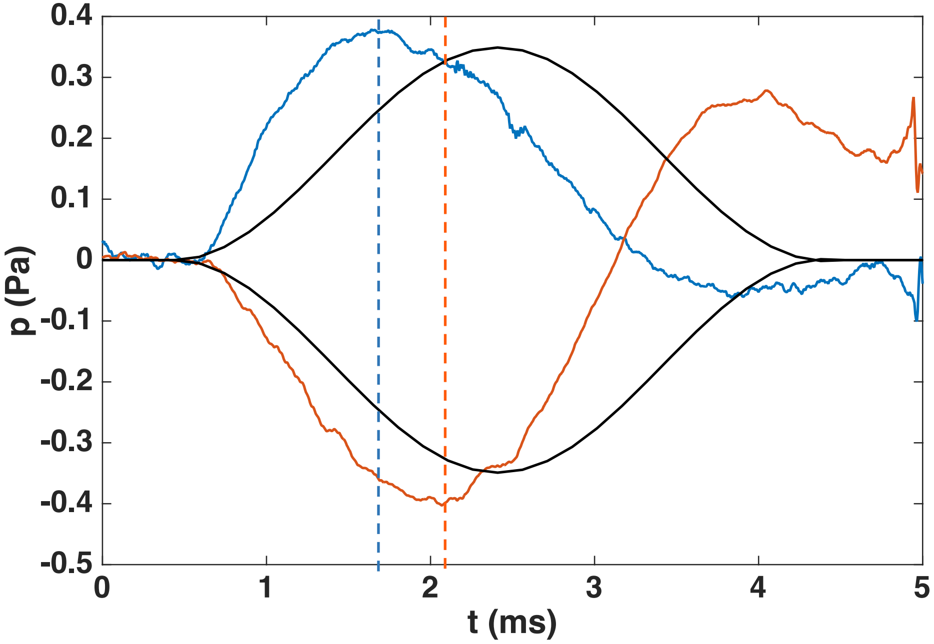
$$V_{TC} = \sqrt{\frac{2\gamma}{\rho_l h}}$$

Taylor-Culick velocity
in term of position

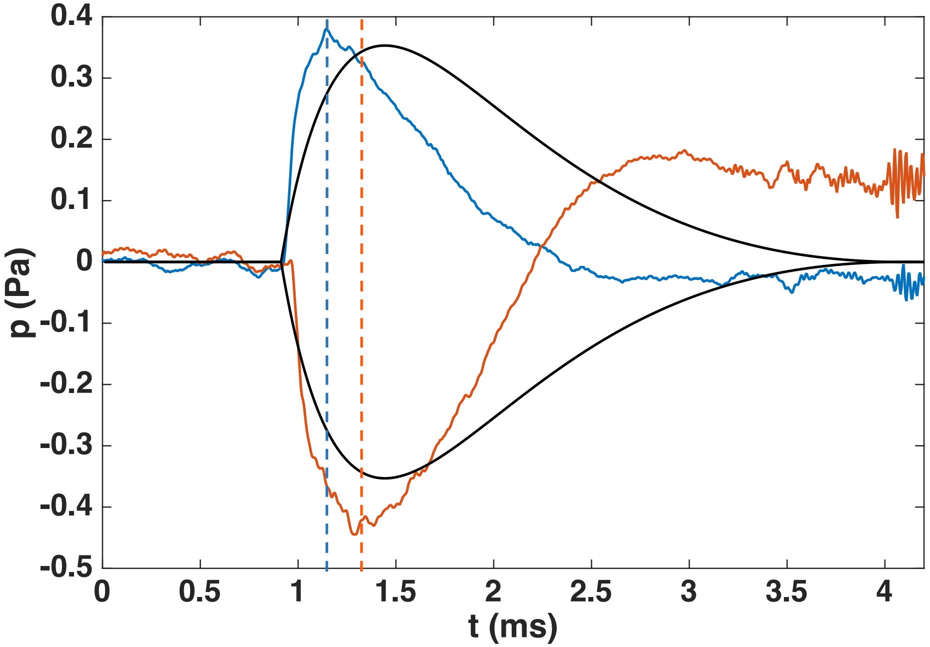


Film thickness

Forced bursting

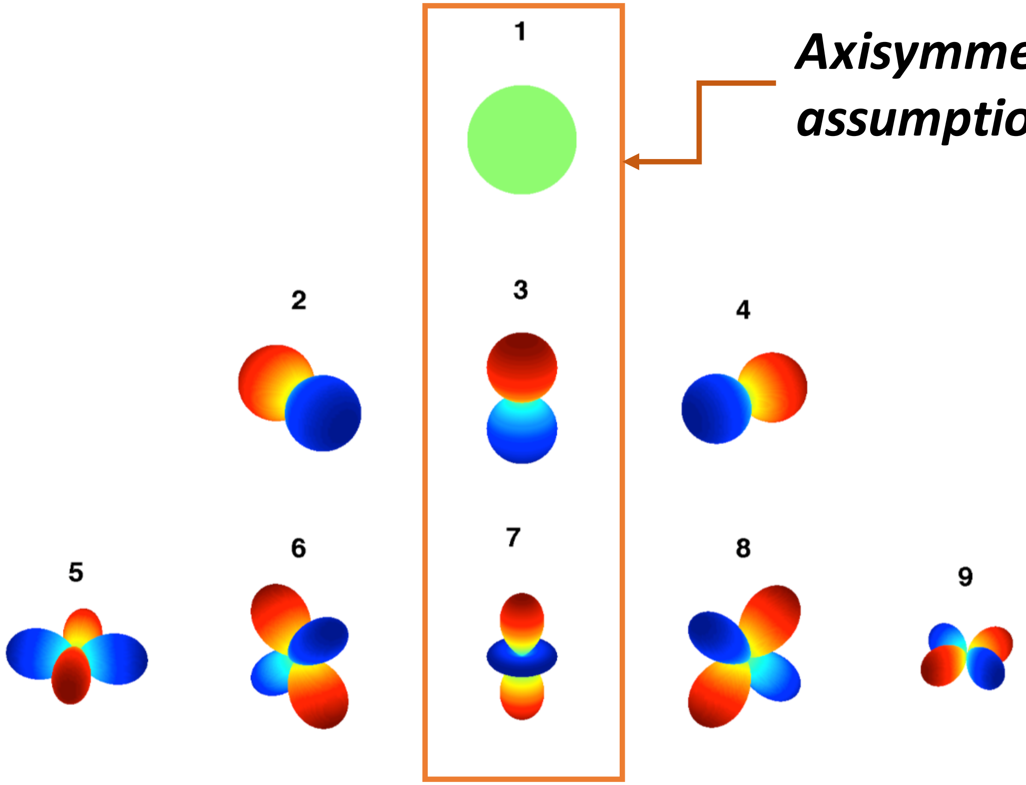


Spontaneous bursting



- Better agreement in the waveform
- Non-symmetric signals

Spherical harmonic decomposition



Axisymmetric assumption

$$p(k,r,\theta) = \sum c_n(k) h_n^{(1)}(kr) Y_n(\theta)$$

$$p_j(t, r_j, \theta_j)$$

⇩ Fourier transform

Nous ne

⇩ Projection

Nous ne pouvons pas afficher cette image pour l'instant.

⇩ Reconstruction

$$p^r_{n,j}(k) = c_n(k) h_n^{(1)}(kr_j) Y_n(\theta_j)$$

⇩ Inverse Fourier transform

Nous ne

Spherical harmonic decomposition

Nous ne pouvons pas afficher cette image pour l'instant.

Z = + 6 mm

Z = 0 mm

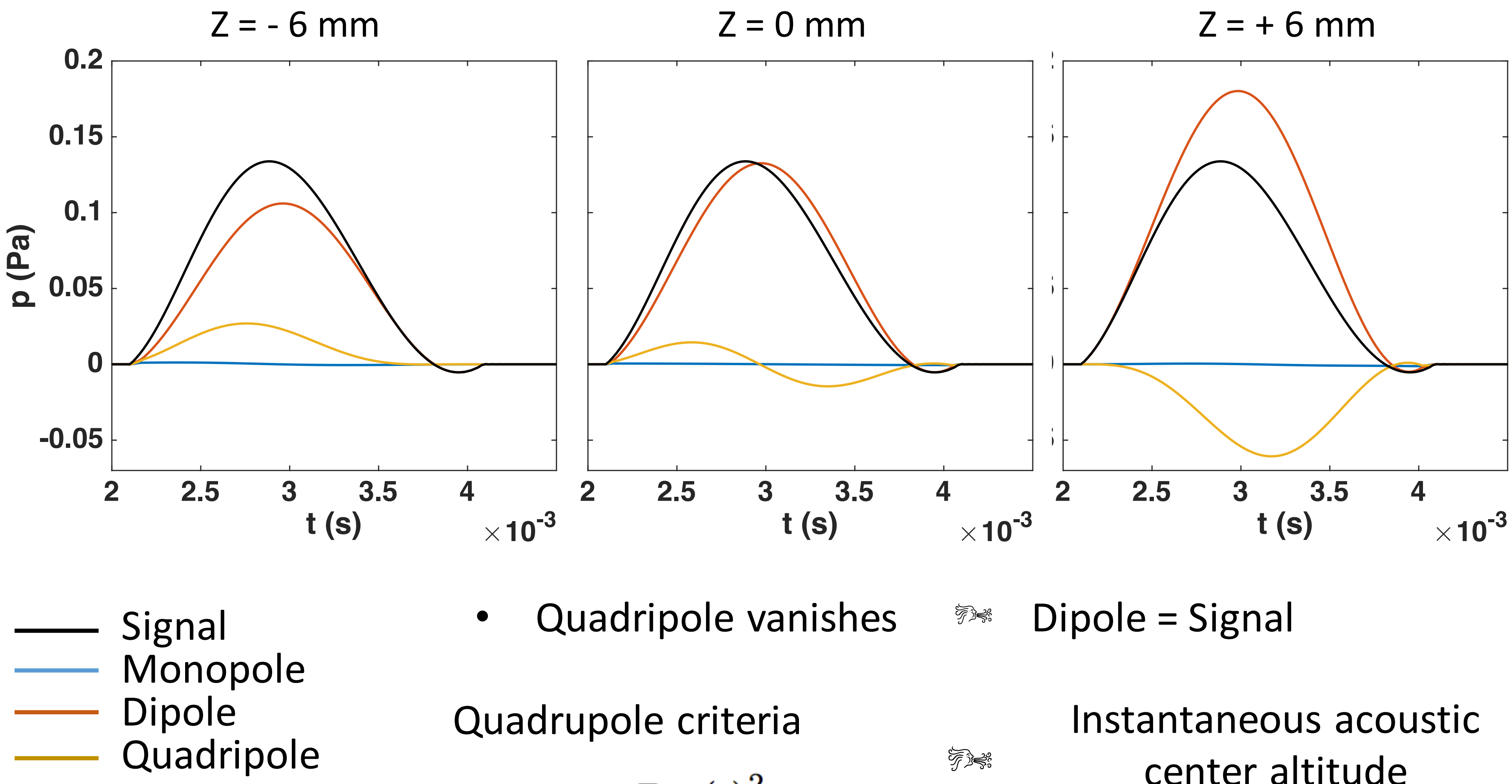
Nous ne pouvons pas afficher cette image pour l'instant.

Z = - 6 mm

— Signal
— Monopole
— Dipole
— Quadripole

Spherical harmonic decomposition

Test case : moving dipole



- Quadripole vanishes → Dipole = Signal

Quadrupole criteria

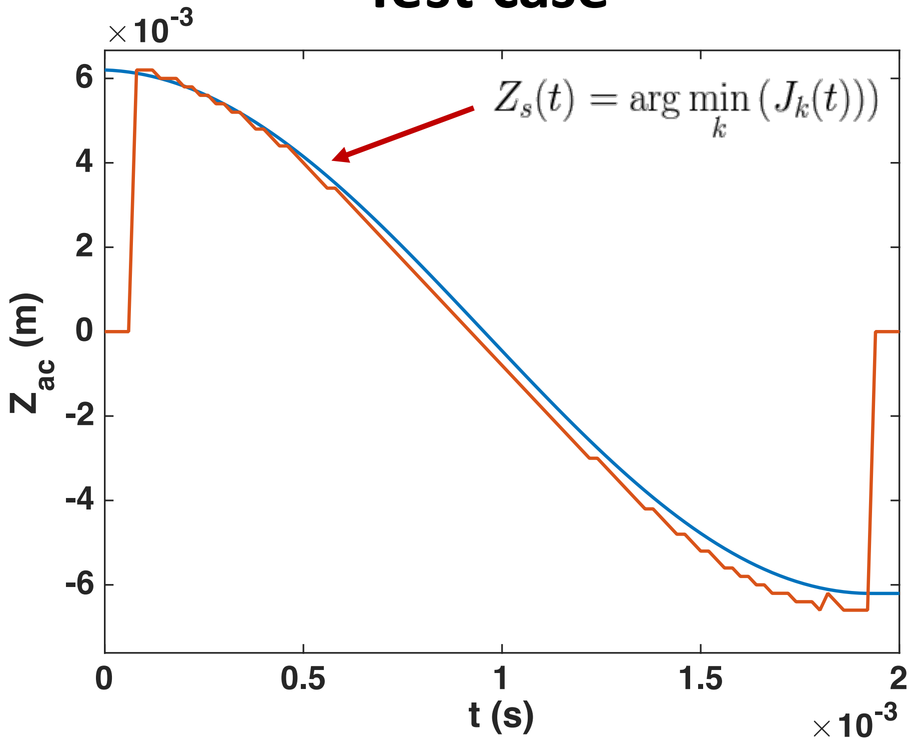
$$J_k(t) = \frac{P_{7,k}(t)^2}{\sum_n P_{n,k}(t)^2}$$

→ Instantaneous acoustic center altitude

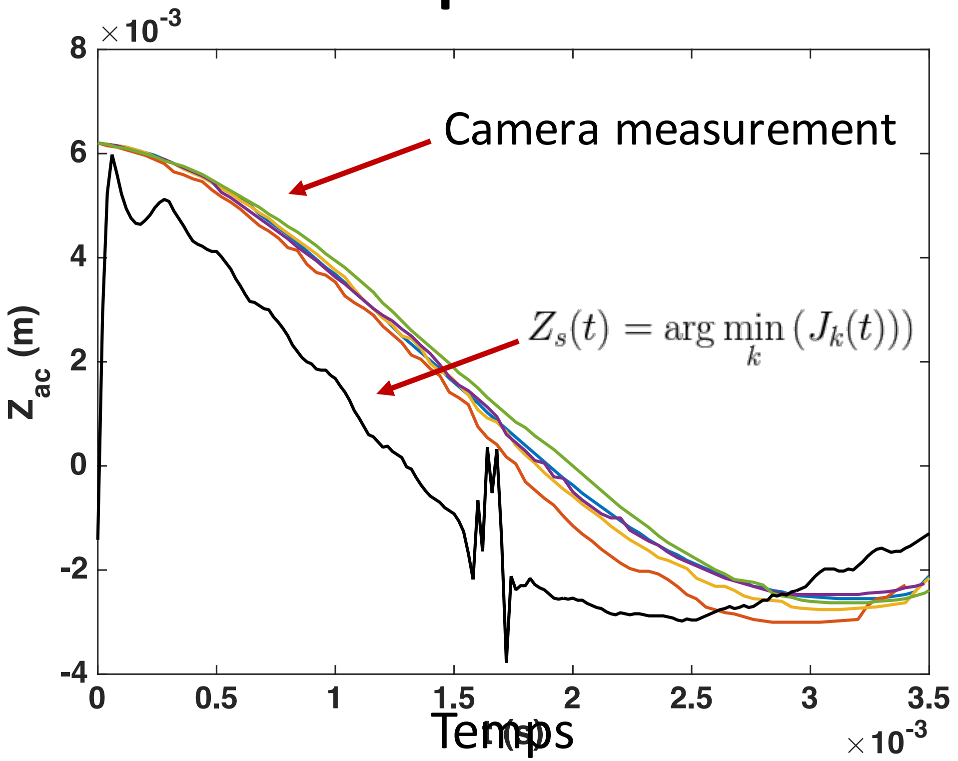
$$Z_s(t) = \arg\min_k \left(J_k(t) \right)$$

Acoustic center tracking

Test case



Experiment



- **Mobile** dipole source
- Source position ≈ liquid rim position

Finite size source model

Simple model :

Integration of the force over time

↓

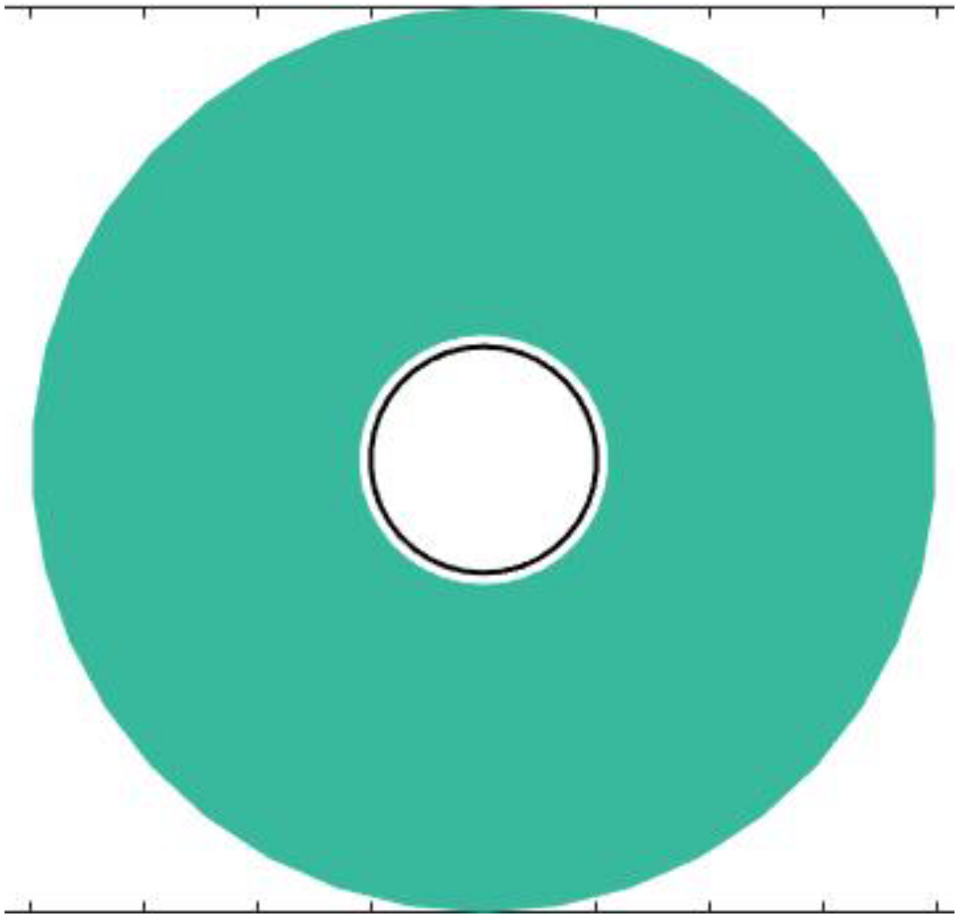
Radiation of the force

Finite size source model :

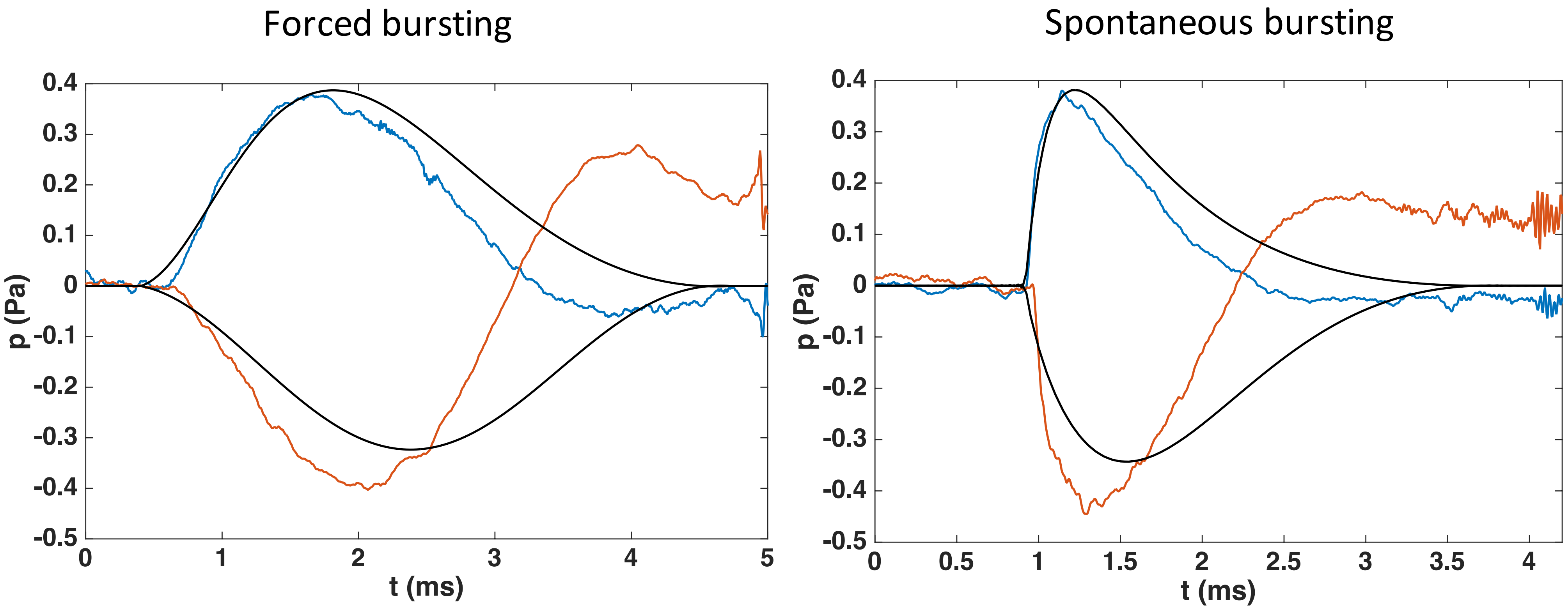
Radiation of infinitesimal forces

↓

Integration of radiations over time



Finite size source model

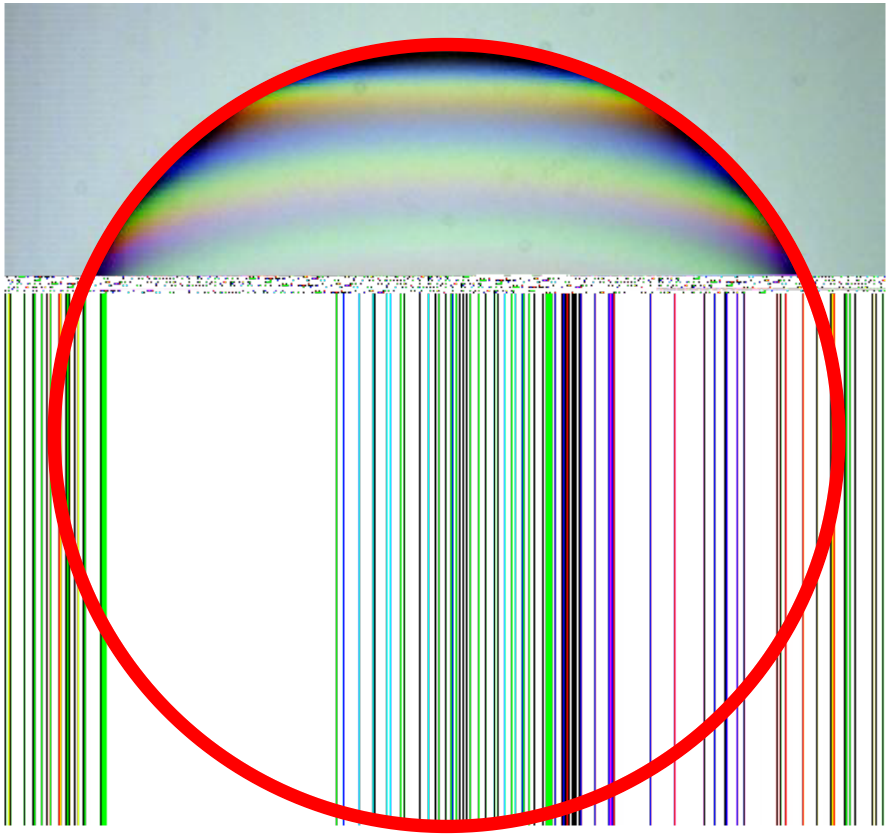

Forced bursting

Spontaneous bursting

- Excellent agreement on the top signal
- Still some discrepancies on the bottom signal

Conclusion

- Understanding and modeling of the "blast-type" wave



Discrepancy on the rim dynamic

Perspectives

- Measurement of hydrodynamic quantities

$$p(\vec{r},t) = \frac{\cos\theta}{4\pi c r}\left(\frac{dF_z}{dt} + \frac{c}{r}F_z\right)$$

$$\Downarrow$$

$$F_z(t) = 4\pi\gamma R\,\sin\left(\frac{v_{TC}}{R}t\right)^2$$

  - Amplitude => bubble radius and surface tension
  - Phase => V_{TC} => Thickness profile

- Extension of this measurement strategy to other phenomenon
  - Bubble coalescence
  - Foam ageing

Thanks for your attention