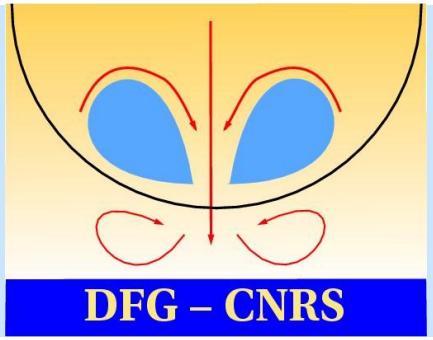
Shocking views of bubble dynamics



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"Micro-Macro Modelling and Simulation of Liquid-Vapour Flows" , IRMA, 23-25 Jan. 2008

Outline

- Introduction
- Laser generation of bubbles
- Bubble collapse – free and disturbed
- Bubble-shock interaction
- Conclusions

Introduction

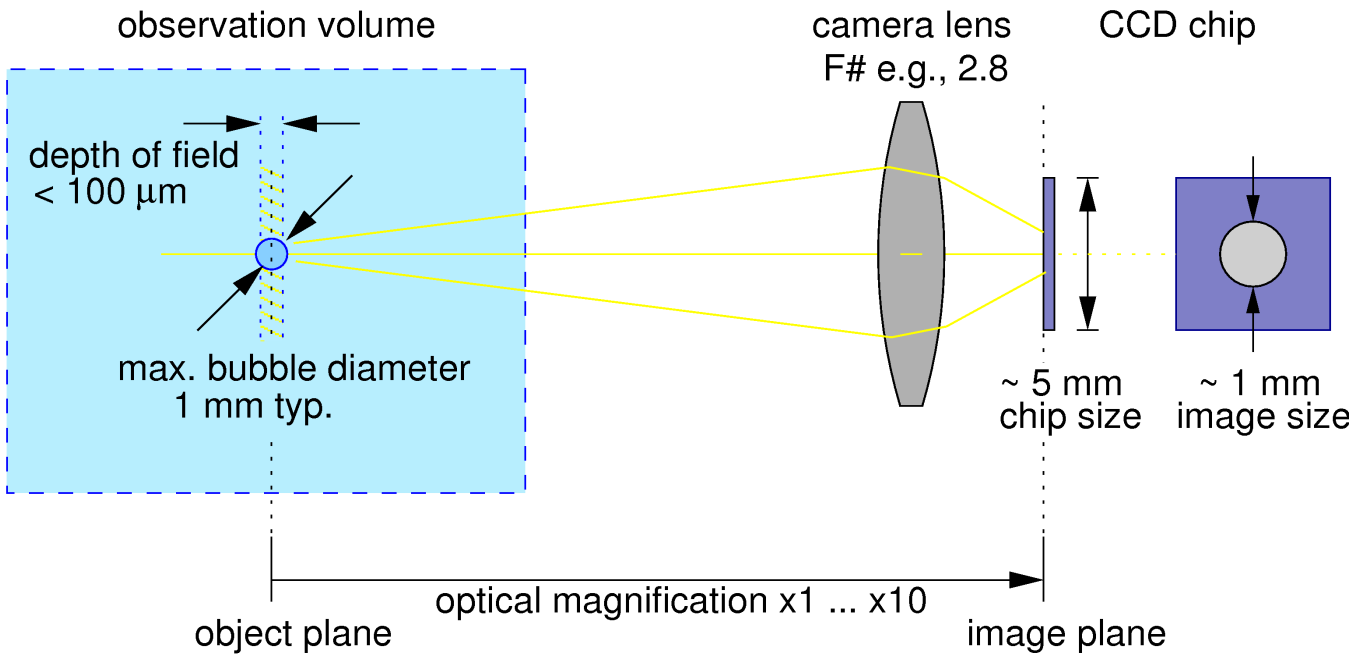
- Bubbles = ubiquitous two-phase systems
  - high-speed liquid flow (turbo-machinery)
  - ultrasonic processing
  - medicine: lithotripsy, laser surgery

- Experimental investigation of single bubble:
  - high-speed imaging
  - acoustic measurements

- Experimental difficulties:
  - range of time scales and spatial scales
  - dynamic generation of secondary bubbles
  - translational motion

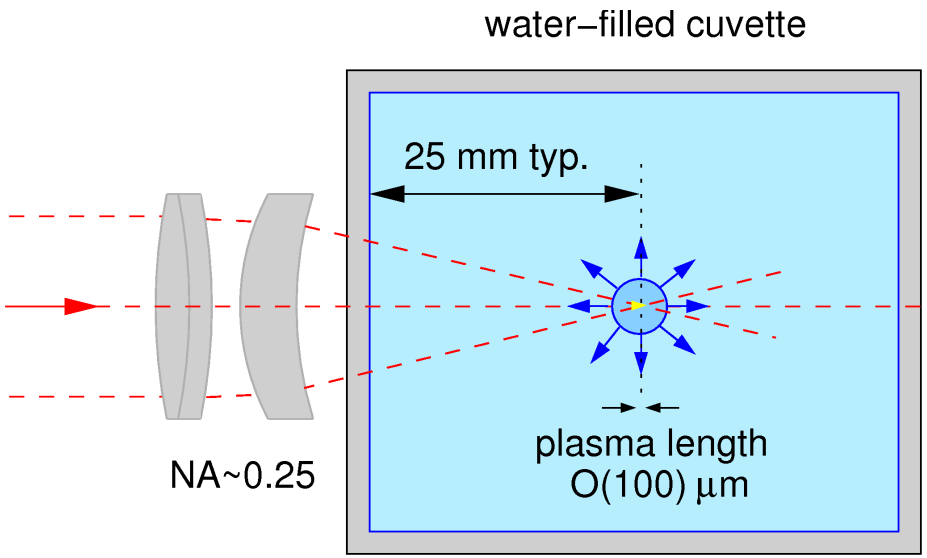
How to image bubbles sharply

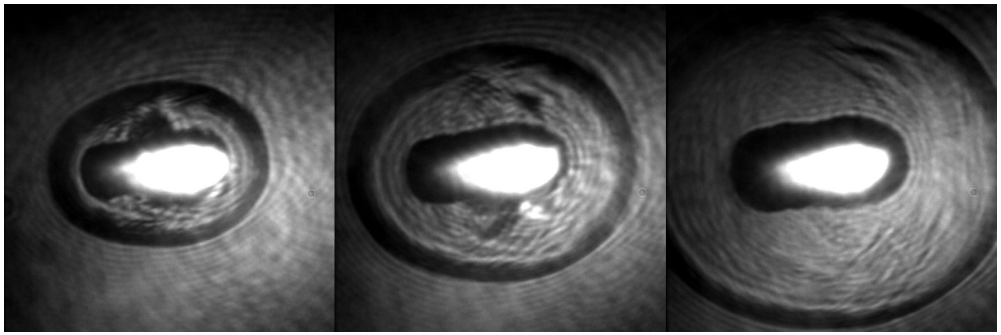
Problem: small depth of field, moving bubbles



Solution: laser generation of bubbles – precise placement and timing

Experimental setup for optic cavitation

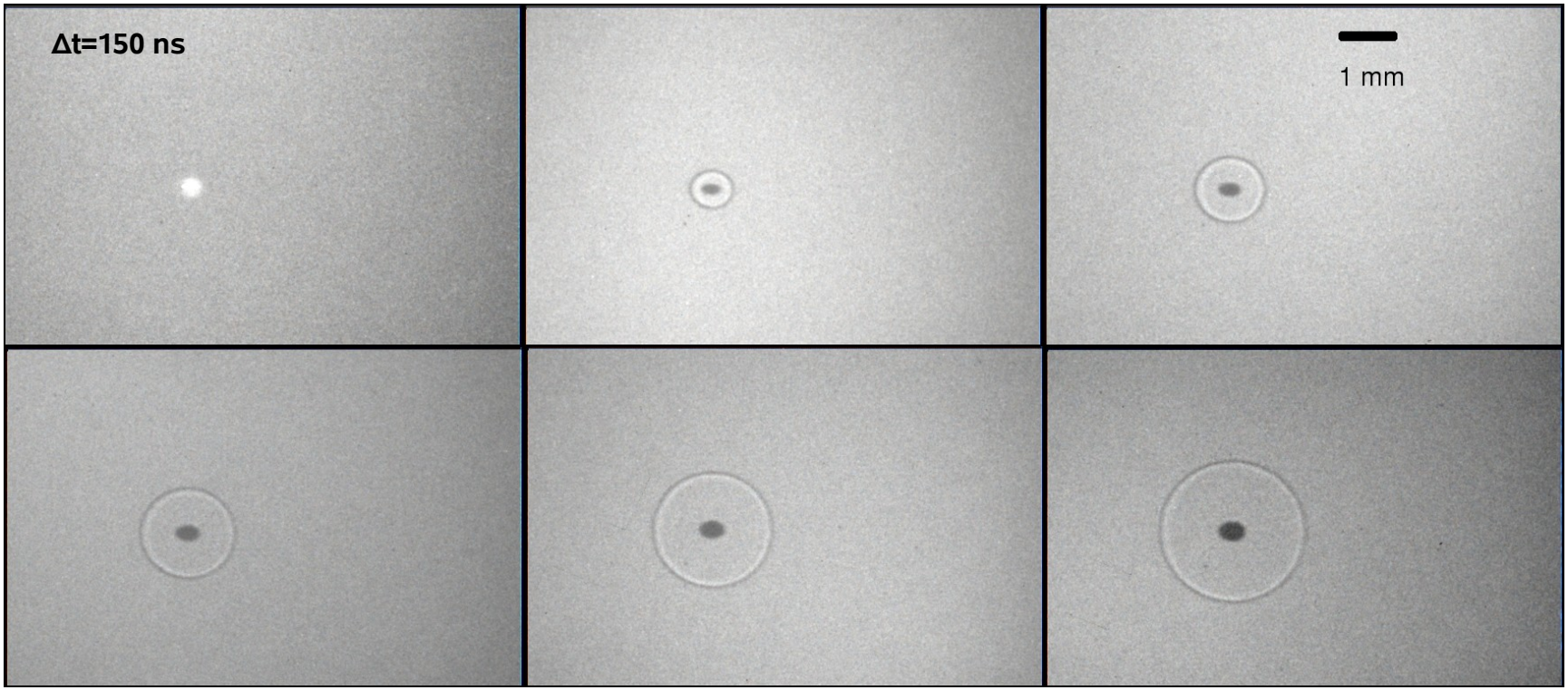




- laser pulse at 1064 nm
- energy $E_p \approx$ a few mJ
- duration 8 ns

- avalanche ionization
- max. T≈ 15000 K
- rapid expansion
- breakdown shock emission

Breakdown shock propagation



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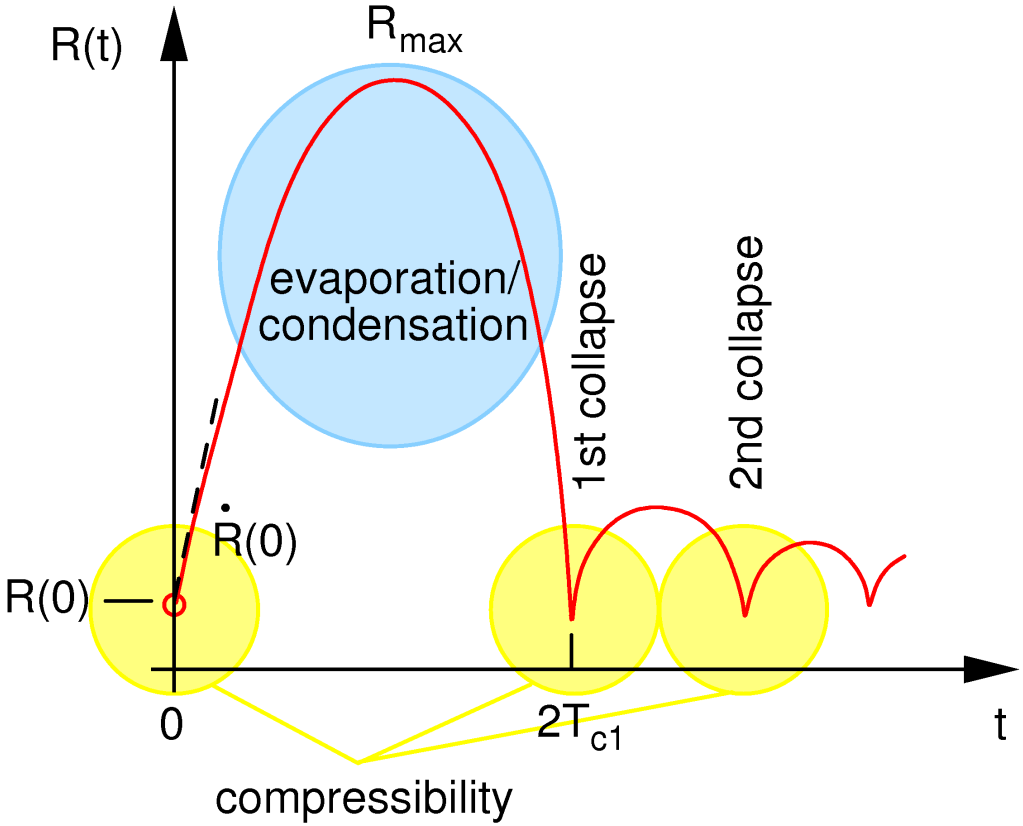
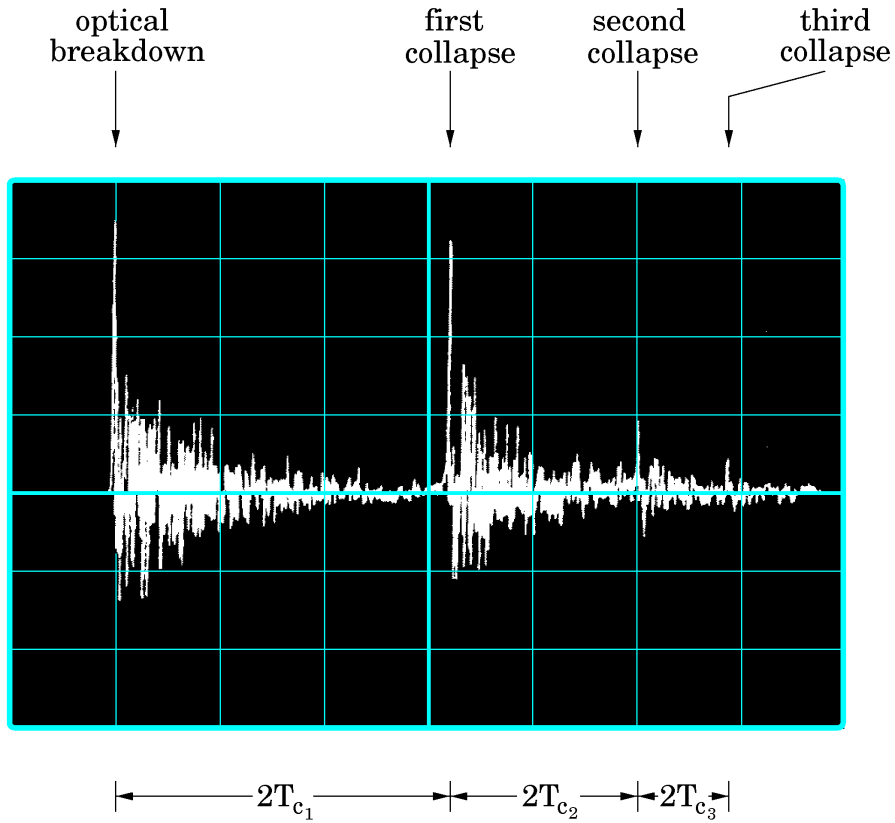
Transient oscillation of free bubble





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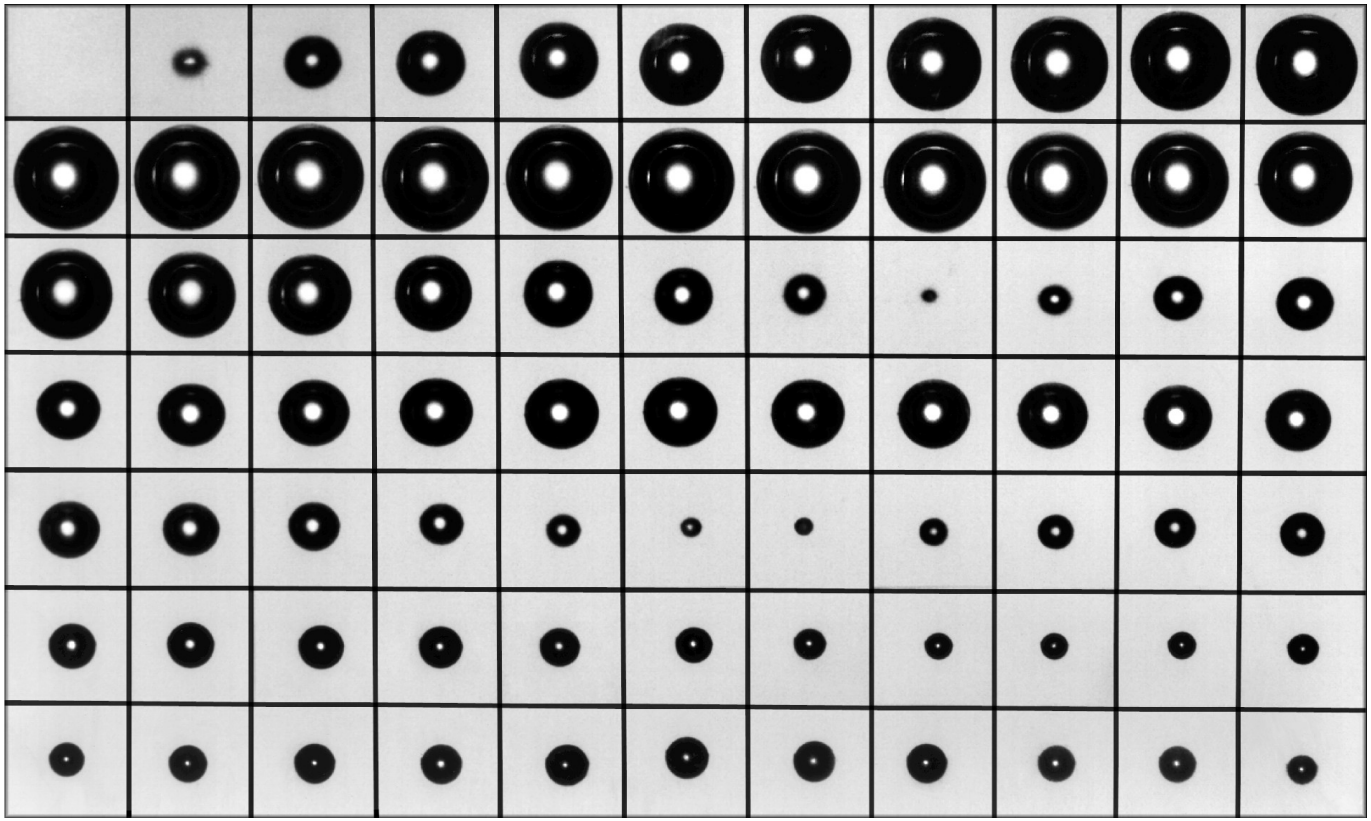
Transient oscillation of free bubble



bubble in silicone oil, 75000 frames/s, max bubble size 2 mm

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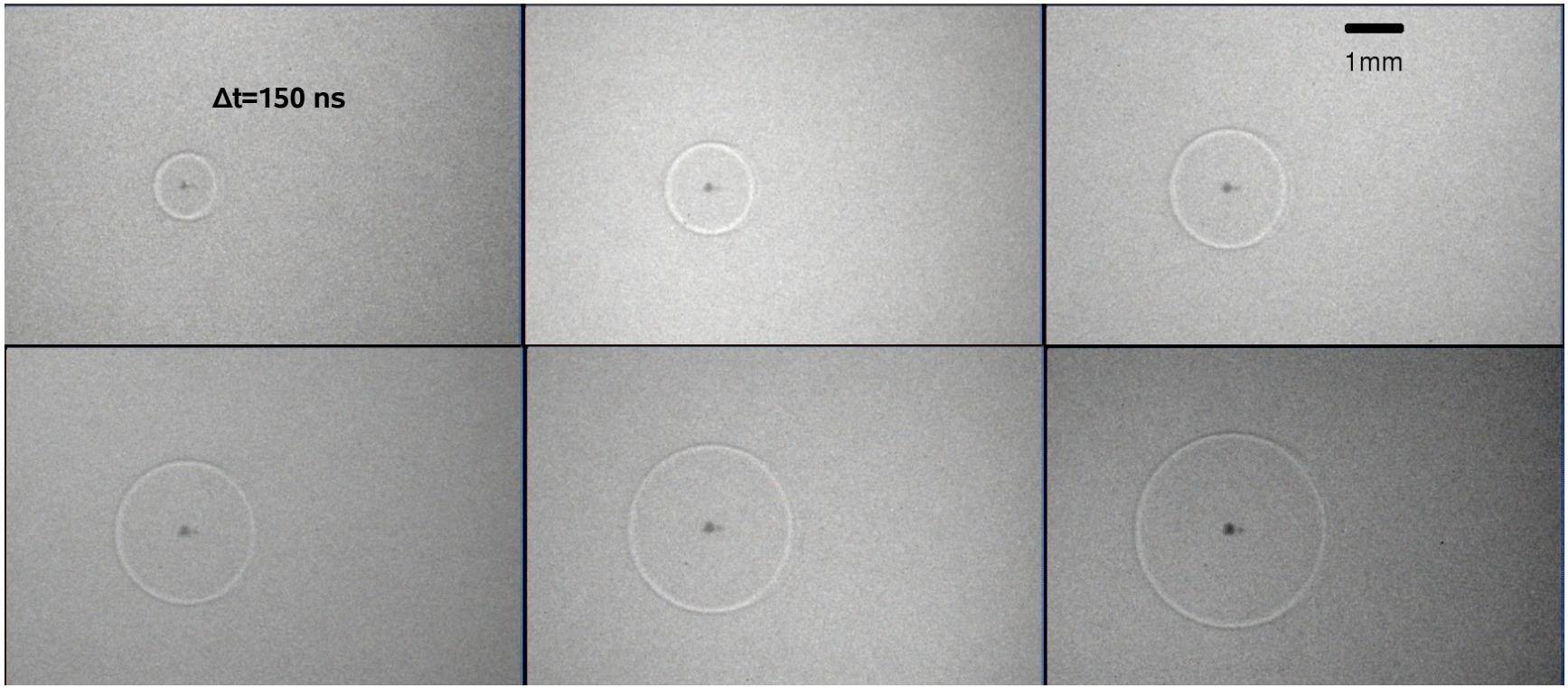
Spherical bubble collapse



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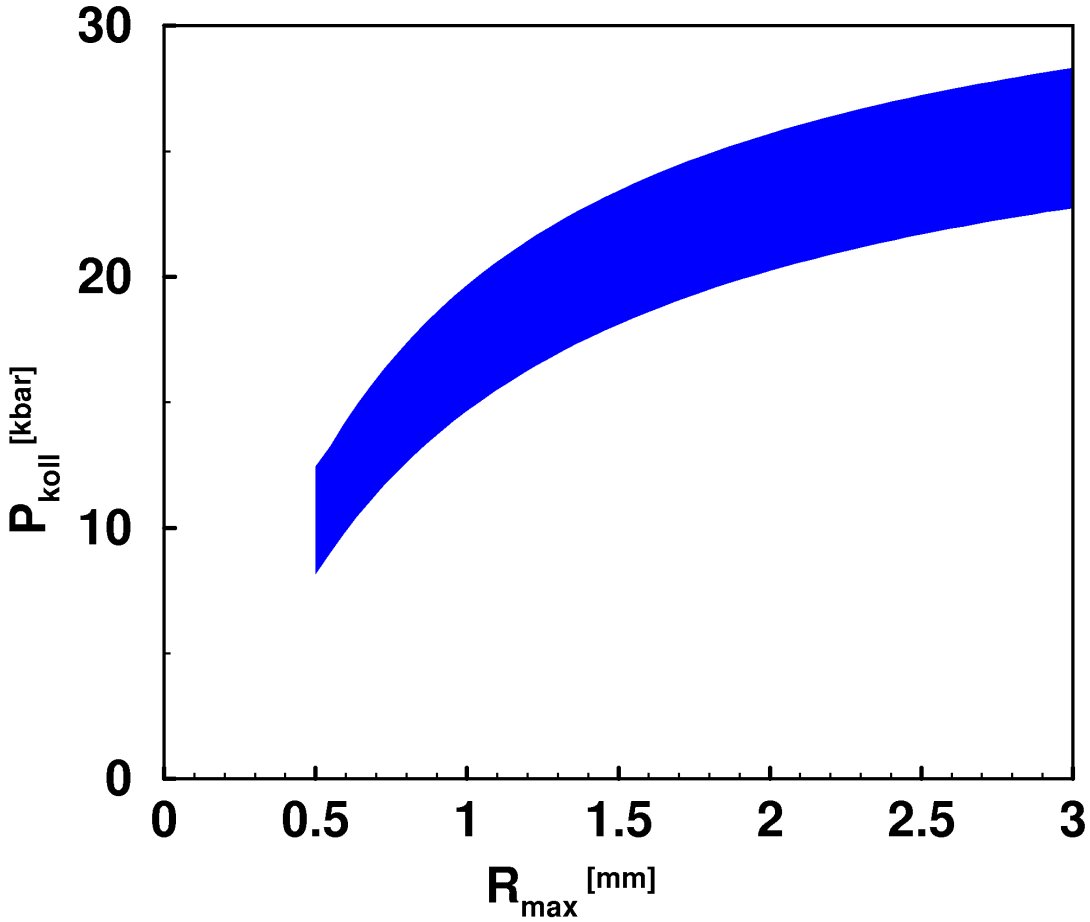
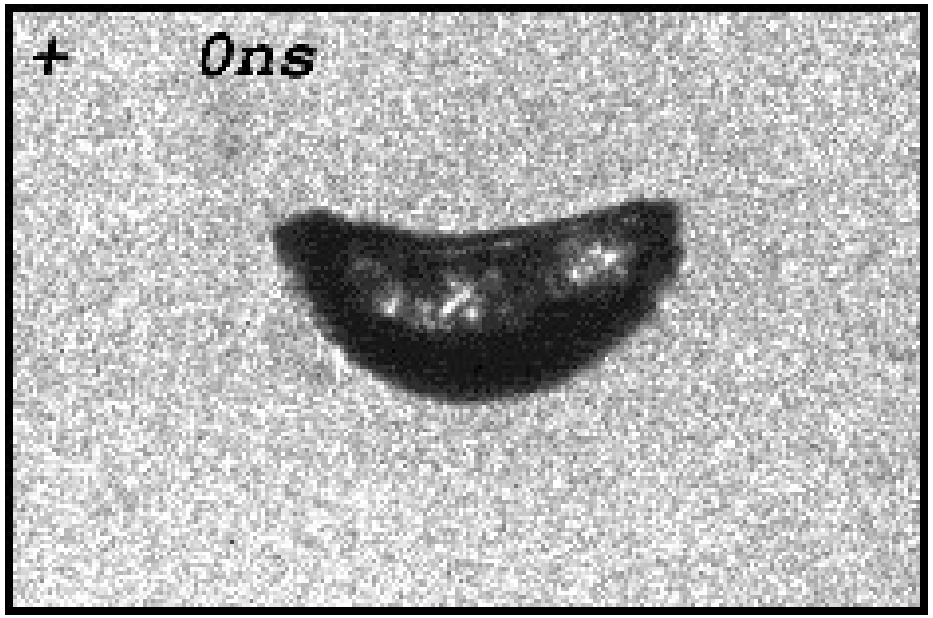
Maximum pressure at collapse



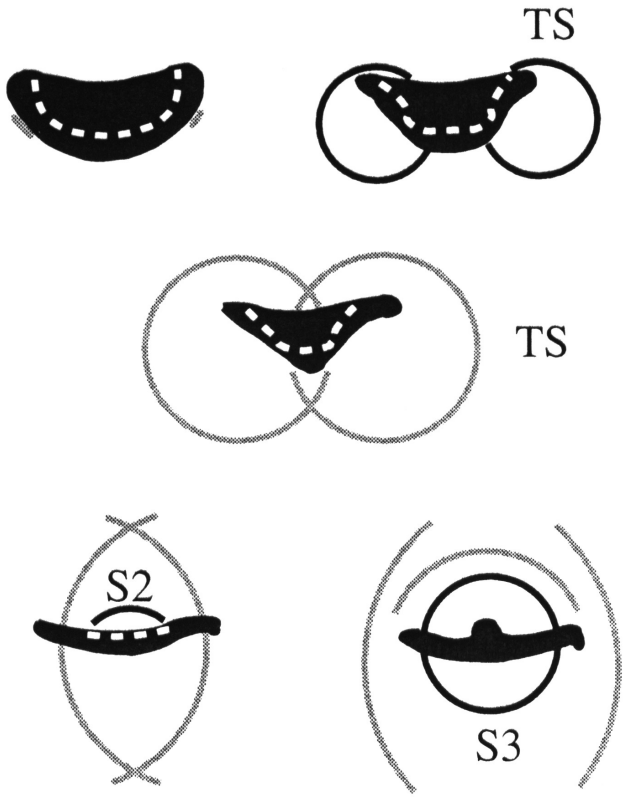
- Pressure at bubble surface
- extrapolation of P(r) measured with a fiber-optic hydrophone

(measurements by Olgert Lindau)

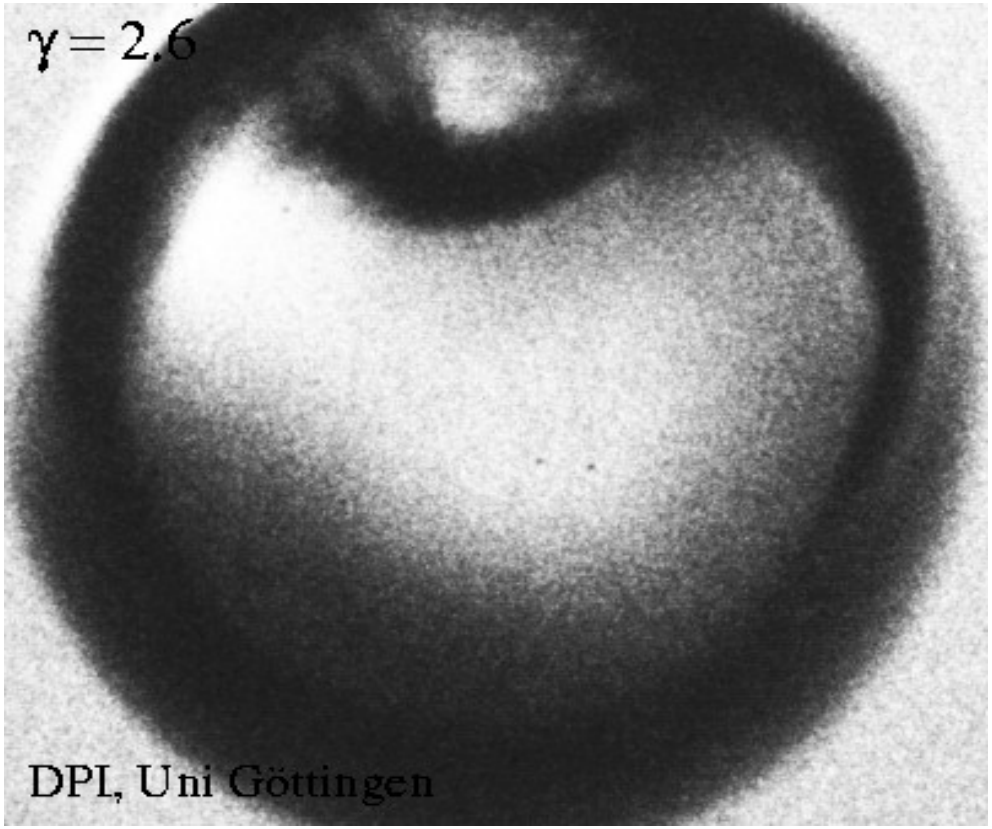
Multiple shocks upon aspherical collapse



γ=2.6, Δt=10 ns, t_{exp}=10 ns, R_{max}=1.5 mm
frame size 1.0 mm x 0.7 mm
(data by O. Lindau)



Counterjet formation

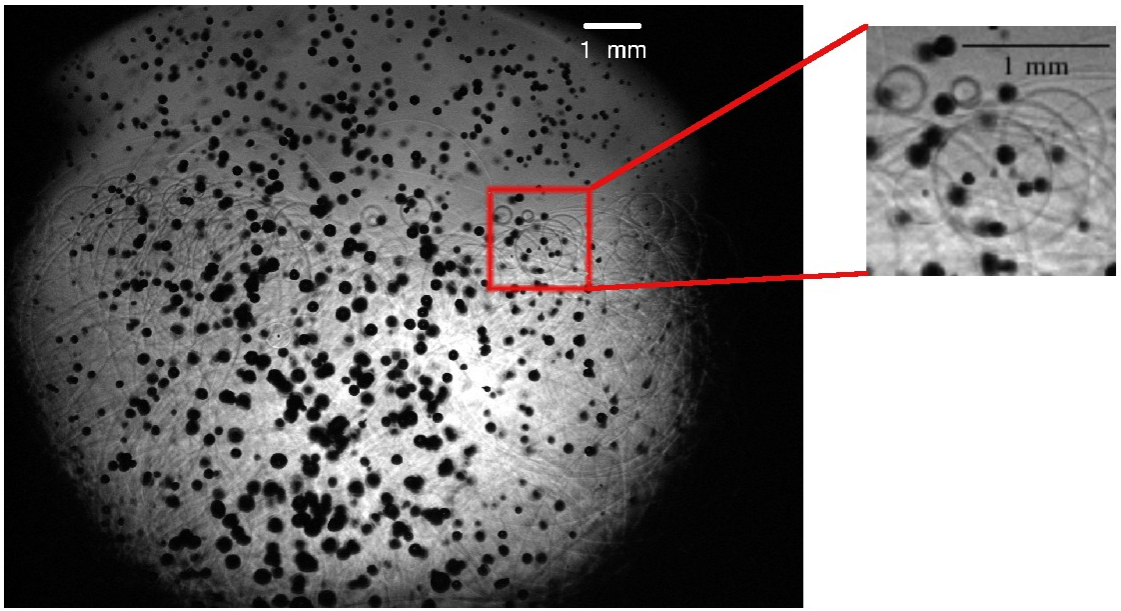


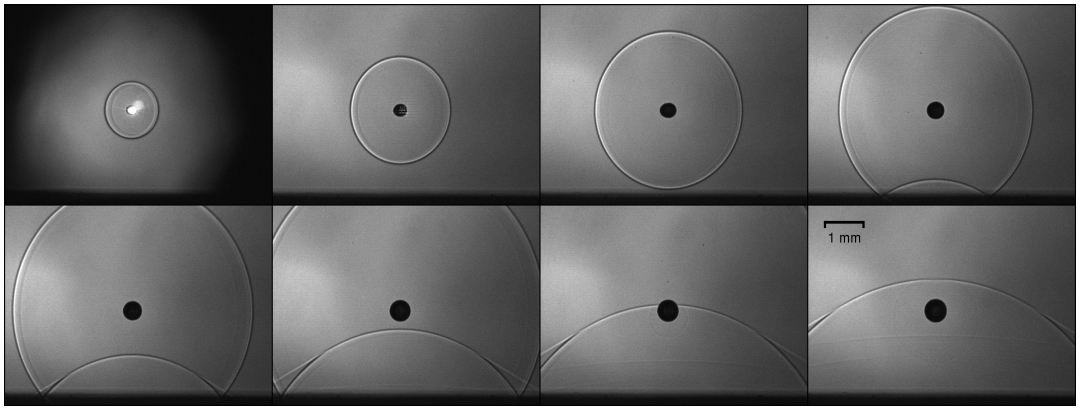
Counterjet =
secondary microcavitation
due to on-axis rarefaction
wave

(data by O. Lindau)

Bubble-shock interaction

- Multiple shock waves in bubble clouds: interaction of bubbles by shock waves in a multi-bubble system



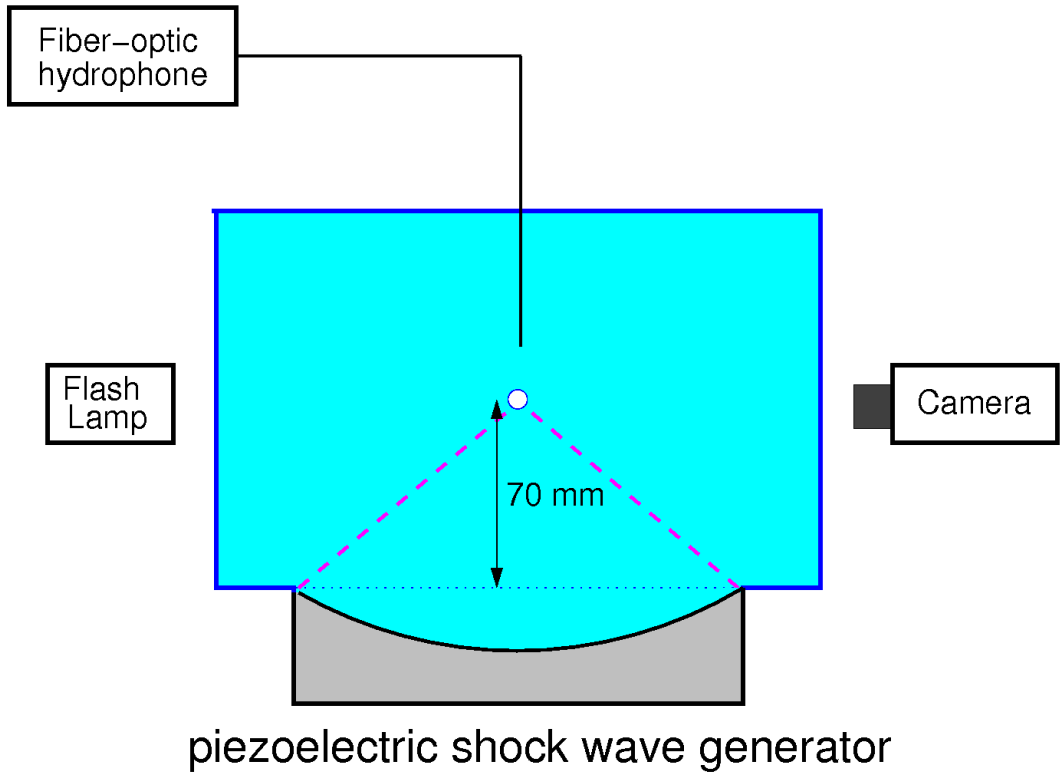


- Reflection of collapse shock waves from boundaries

Δt=400 ns **Dennis Kroeninger**

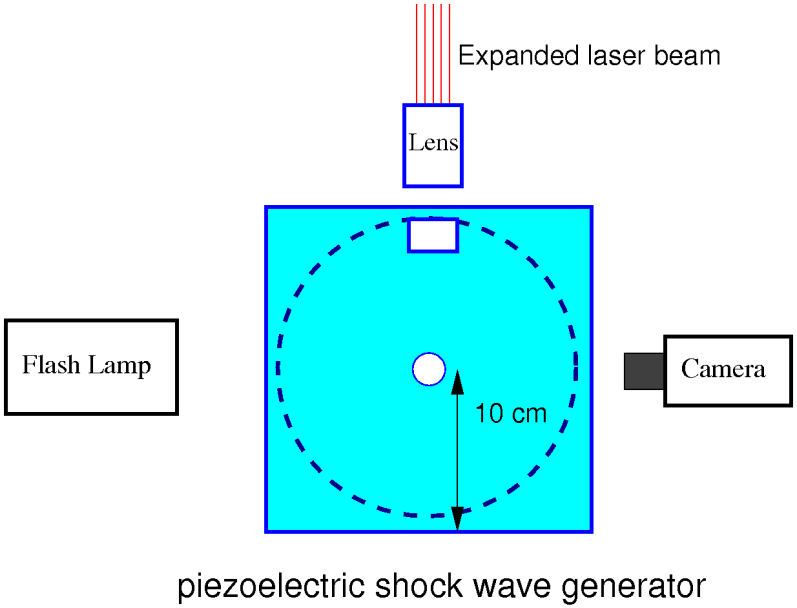
Bubble-shock interaction

- interaction of bubbles with external shock waves (e.g., lithotripsy)

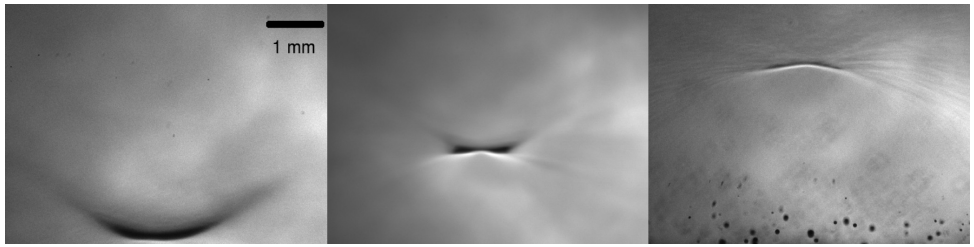


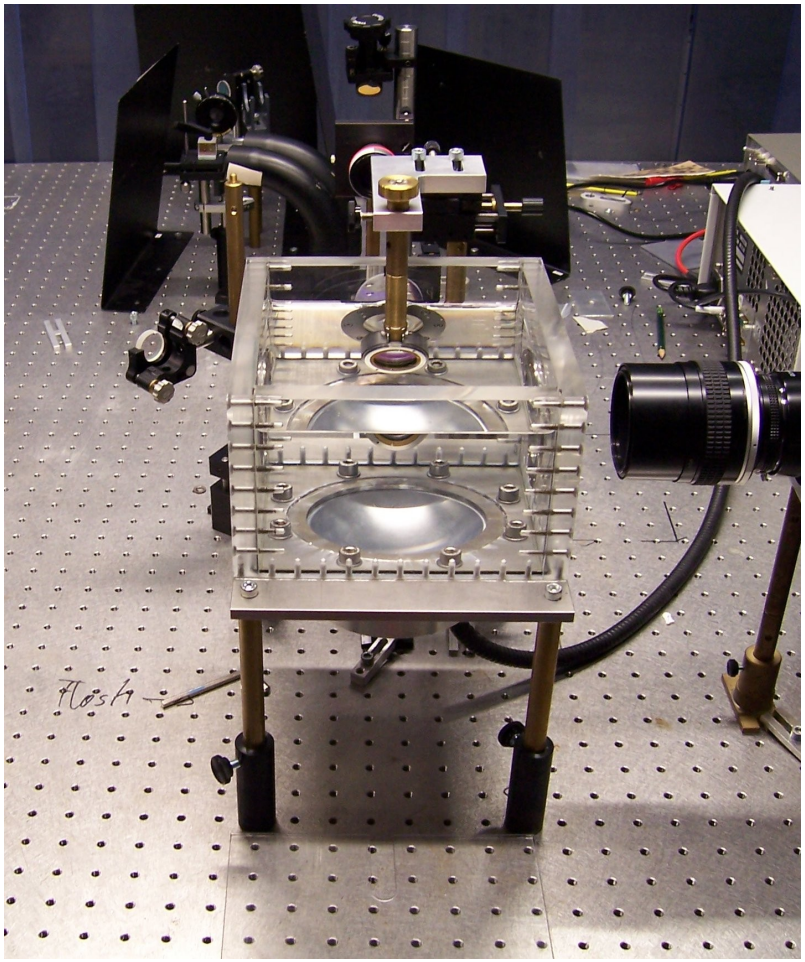
Experimental setup for bubble-shock interaction studies

Experiment on bubble-shock interaction

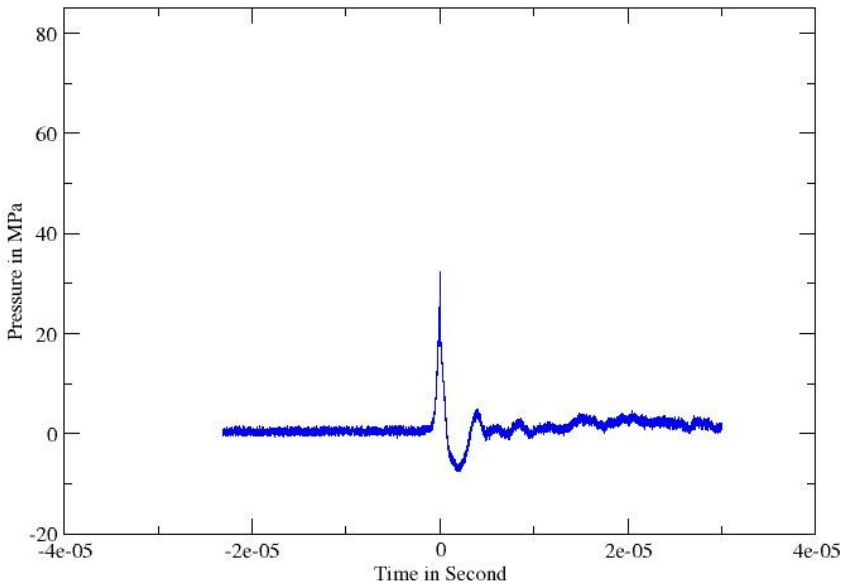


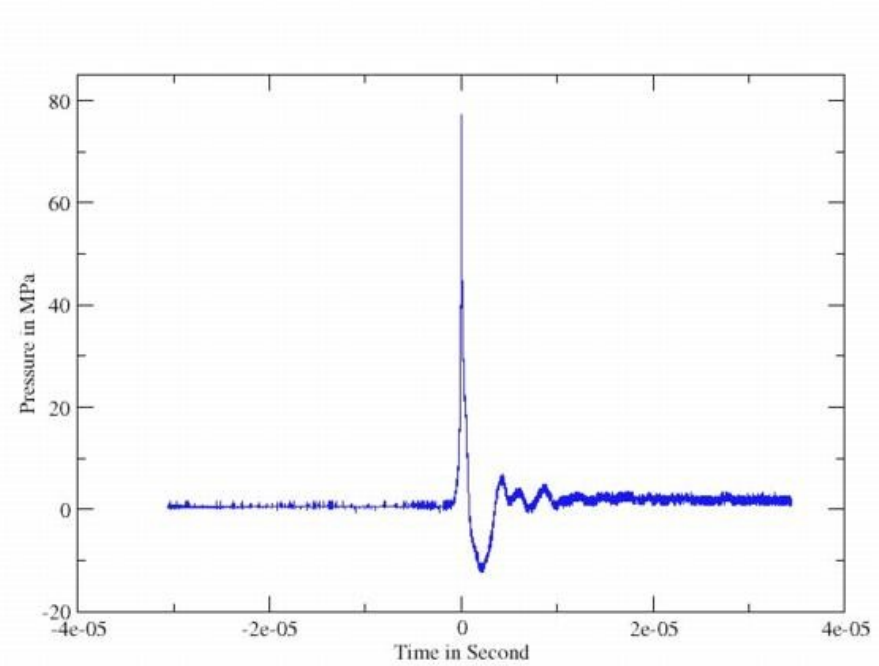
piezoelectric shock wave generator





Pressure profile of applied shock





At 1 mm above the focus :

P_{max} = 32 Mpa
FWHM $_{comp}$ = 0.36 µs
FWHM $_{tens.}$ = 1.8 µs

P_{max} = 77 Mpa
FWHM $_{comp.}$ = 0.1µs
FWHM $_{tens.}$ = 2.2 µs

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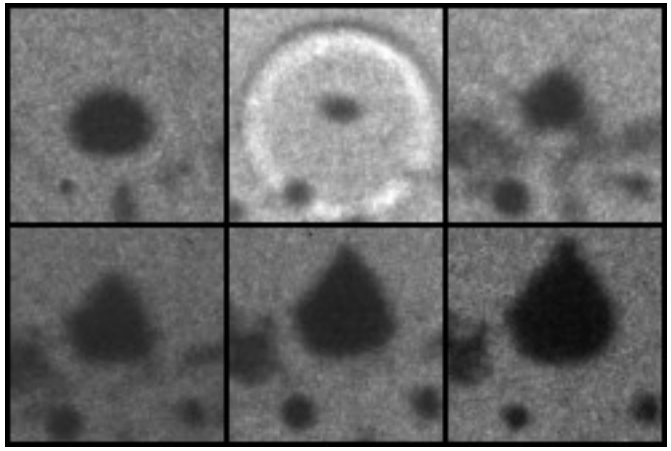
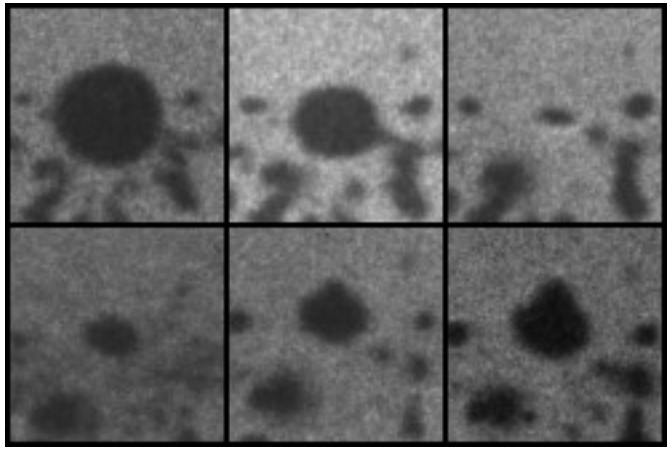
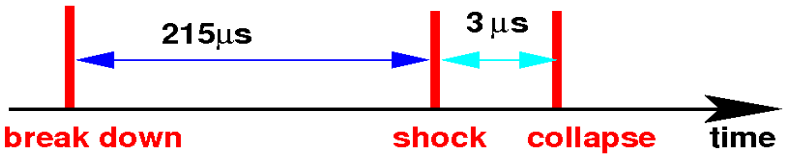
Bubble-shock interaction

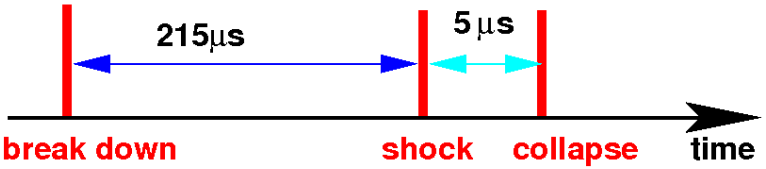
- asymmetric collapse with jet formation
- reduction of collapse time





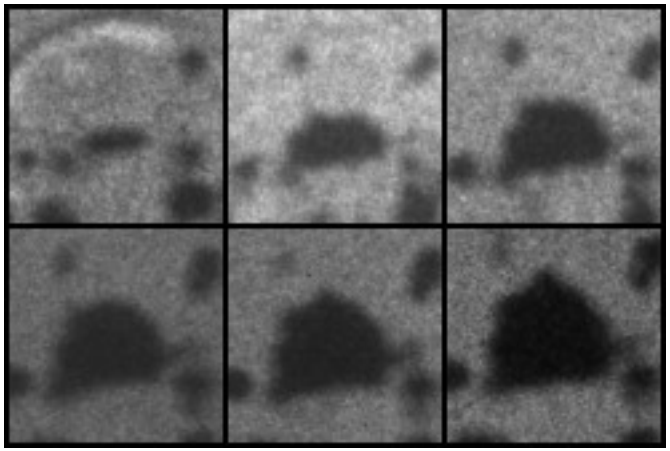
Δt= 1μs frame width = 1.44 mm

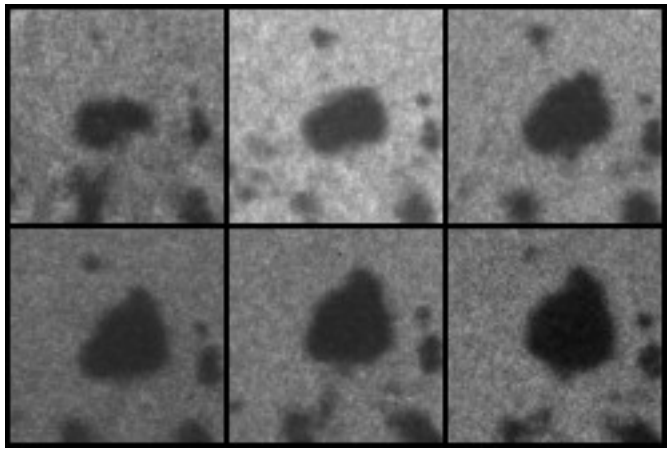




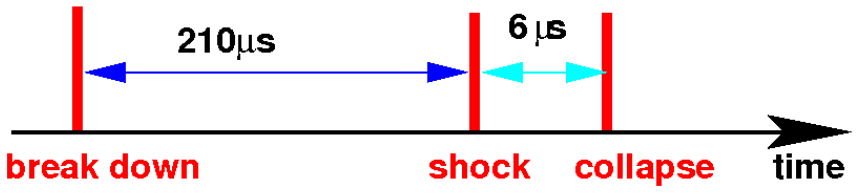
Bubble-shock interaction

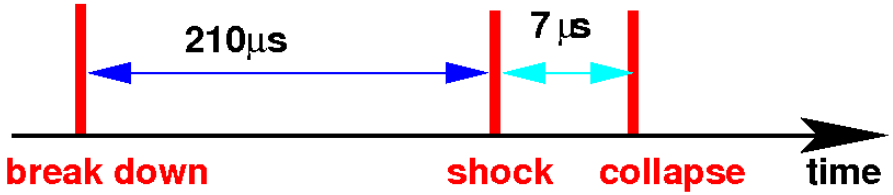
shock arrives 210 µs after breakdown (bubble near collapse)





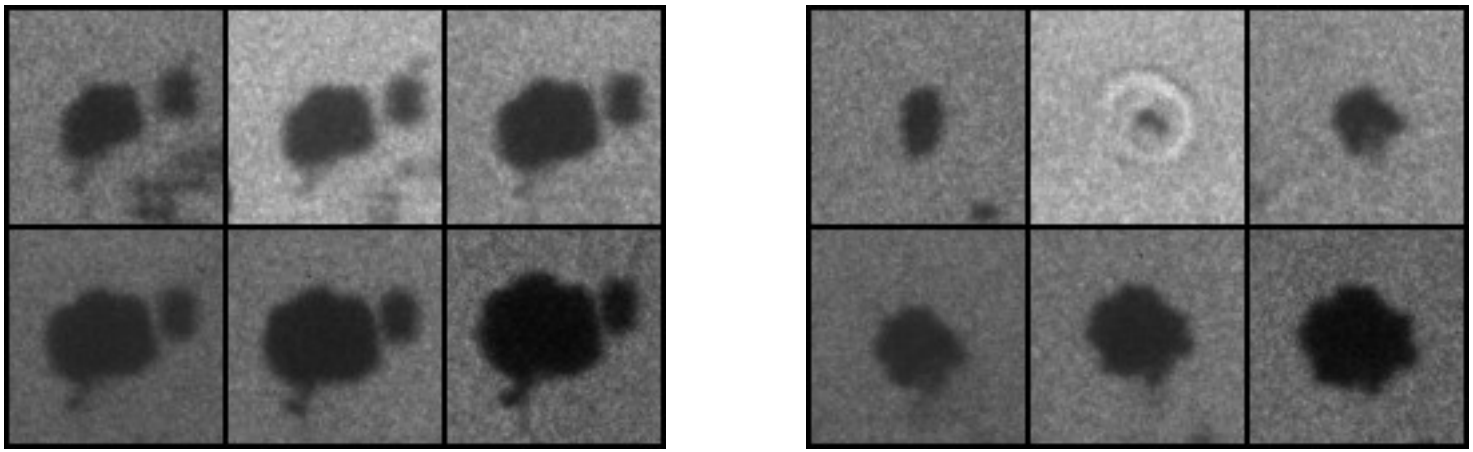
Δt= 1µs frame width = 1.44 mm



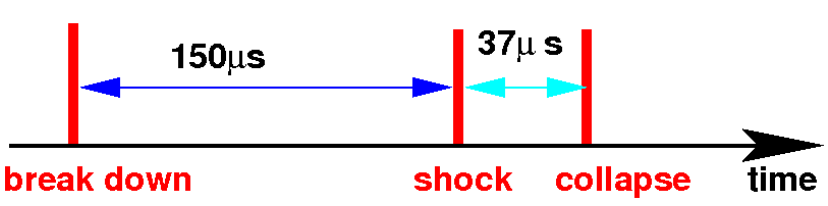


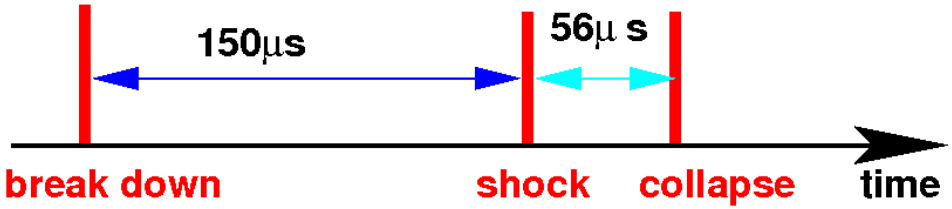
Bubble-shock interaction

shock arrives 150 µs after breakdown (bubble collapsing)



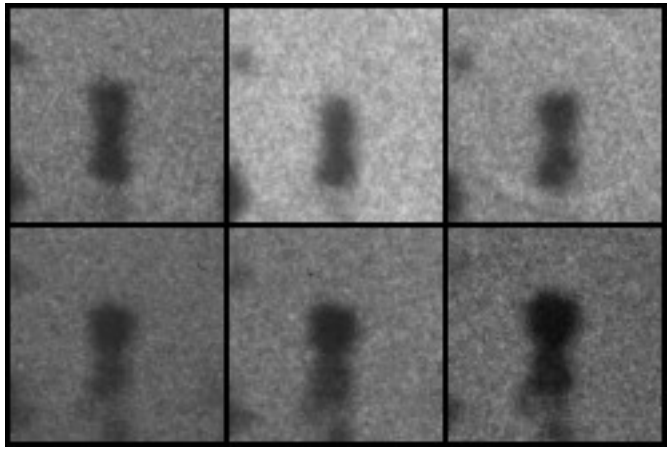
Δt= 1µs frame width = 1.44 mm

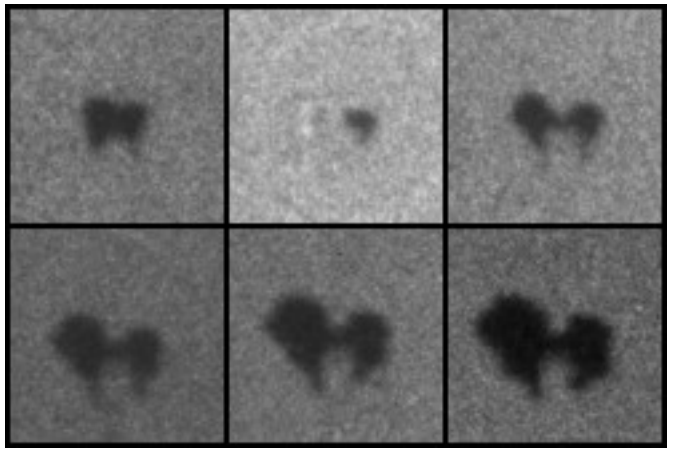




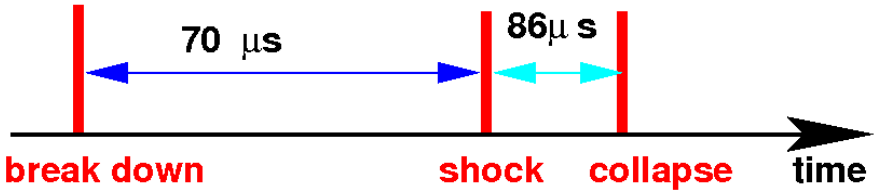
Bubble-shock interaction

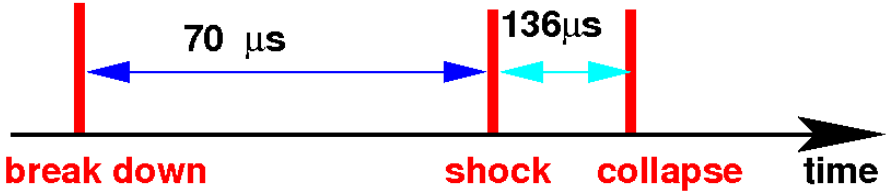
shock arrives 70 µs after breakdown (bubble expanding)



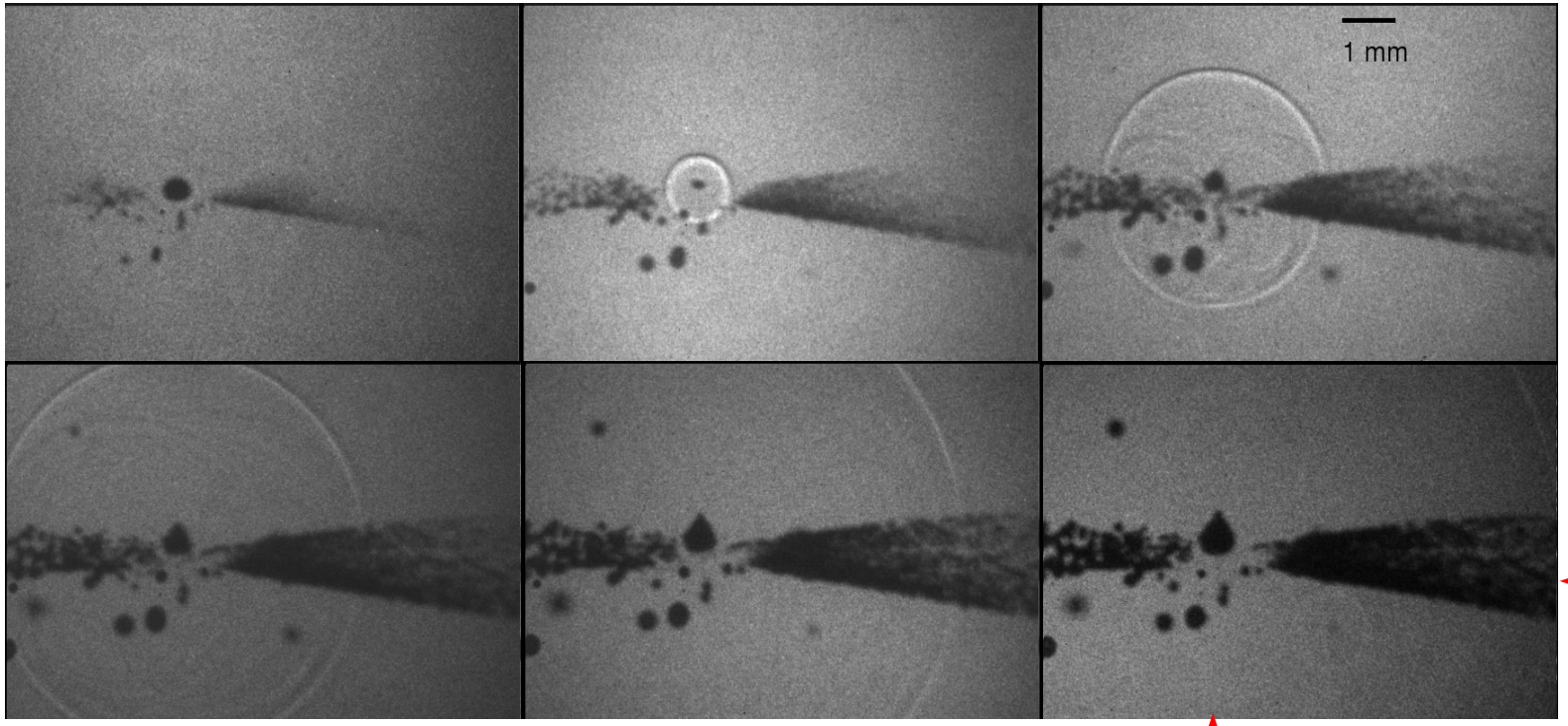


Δt= 1µs **frame width = 1.44 mm**





Secondary cavitation



Conclusions & Outlook

- bubble collapse:
  - strong shock waves possible
  - complicated multi-shock wave scenario upon asymmetric collapse
  - counter jet formation
- bubble-shock interaction:
  - shortening of collapse time
  - jet formation
  - secondary cavitation induced by rarefaction waves
- further experiments:
  - measurements of jet velocities and shock-induced flow
  - dependence on bubble size
- shock propagation in bubble clusters