Experimental investigation of cavitation inception in a confined liquid layer by laser-induced pressure pulses

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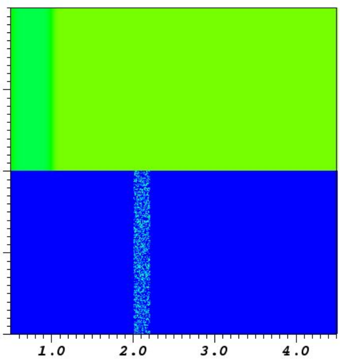
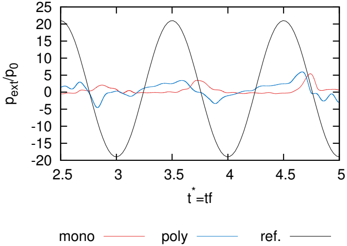
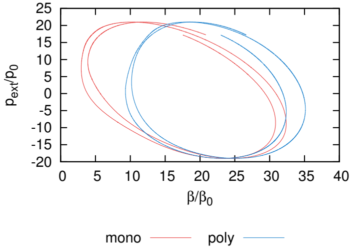
C. De Sainte (DGA/MRIS), G Tahan (IRDL), L. Videau (CEA)

CACHMAP ANR-ASTRID project

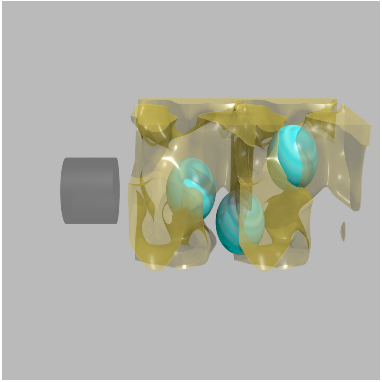
Can pre-existing bubbles protect the structure?







Cluster response $\Delta p = 20$ atm

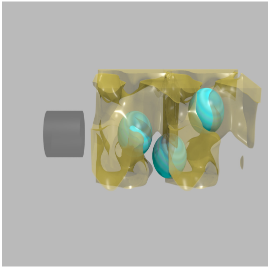


Reducing damage:

Does **cavitation inception** plays a role on the system's dynamics for strong impact

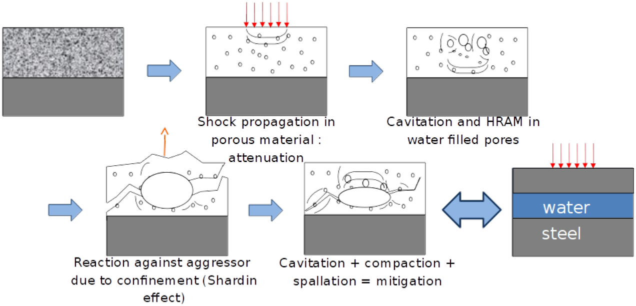
It is not obvious it will occur!!!

If we manage, it is interesting because it is a reversible *fracture* process



Reducing damage:

The appereance and propagation of cracks dissipate a large amount of energy

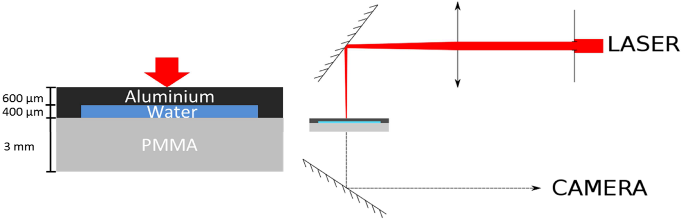


It is an irreversible process!!!

Proof of concept:

High intensity pressure waves in confined water to see if we can observe cavitation

Experimental setup at IRDL, ENSTA-Bretagne:



Quanta Ray Pro 350-10

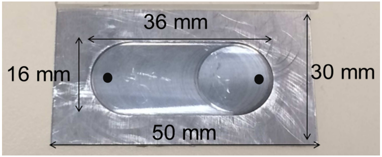
Spectra-Physics

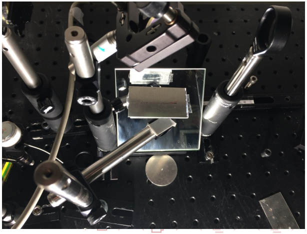
$E_{max} = 3.7$ J

$\lambda = 1064$ nm

Focal region: 3mm

Power ≈ 0.5 GW/cm^2





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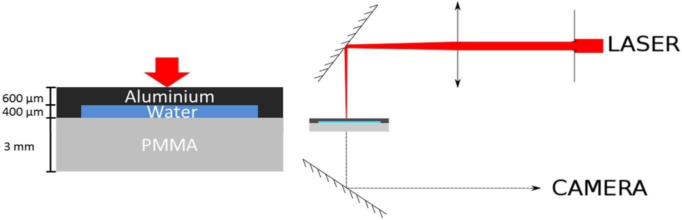

Quanta Ray Pro 350-10

Spectra-Physics

$E_{max} = 3.7$ J

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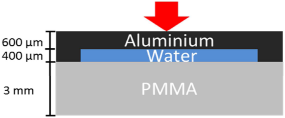
Focal region: 3mm

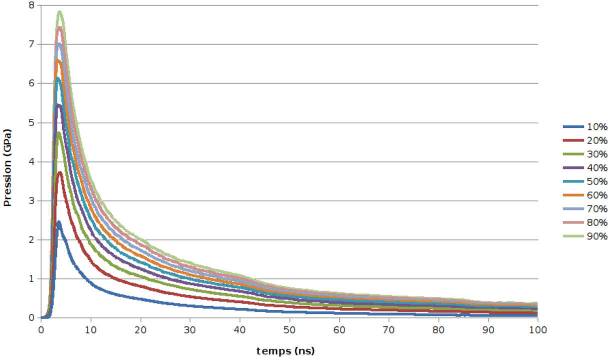
Power $\approx$ 0.5 GW/cm^2

Advantage: Controllable, small volume $(e = 250, 400, 750\mu m)$

Proof of concept:

High intensity pressure waves in confined water to see if we can observe cavitation





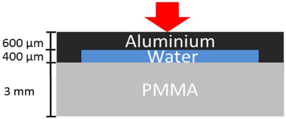
Advantage: Controllable, small volume $(e = 250, 400, 750 \mu m)$

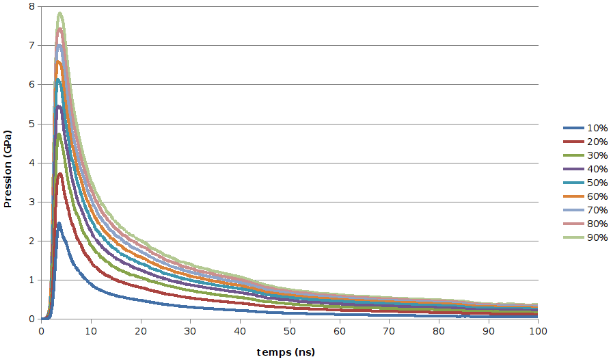
Disadvantage: short pulse duration (high frequency)

The shorter the pulse duration, the higher the energy to induce cavitation

Proof of concept:

High intensity pressure waves in confined water to see if we can observe cavitation





Characteristic times

Excitation ≈ 10 ns (f = 0.1 GHz)

Wave propagation in Al ≈ 0.1 μs

Wave propagation in Water ≈ 0.13-0.5 μs

Wave propagation in PMMA ≈ 1 μs

First qualitative observations:

Focal region:

D = 3.3mm

Water thickness:

$e = 750\ \mu m$

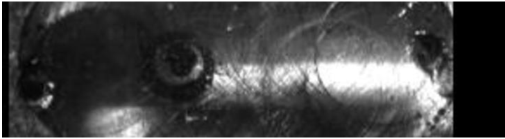
Framerate:

300000 fps

Video duration:

1 ms

$E = 20\ \%$



First qualitative observations:

Focal region: $E = 5\ \%$

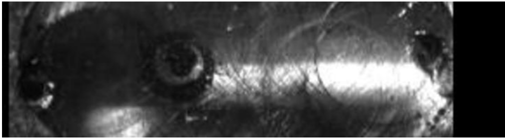
$D = 3.3$mm

Water thickness: $E = 10\ \%$

$e = 750\ \mu$m

Framerate: $E = 20\ \%$

300000 fps



Video duration: $E = 40\ \%$

1 ms

$E = 80\ \%$

First qualitative observations:

Focal region:

$D = 3.3mm$

Water thickness:

$e = 750\ \mu m$

Framerate:

300000 fps

$E = 5\ \%$

$E = 10\ \%$

$E = 20\ \%$

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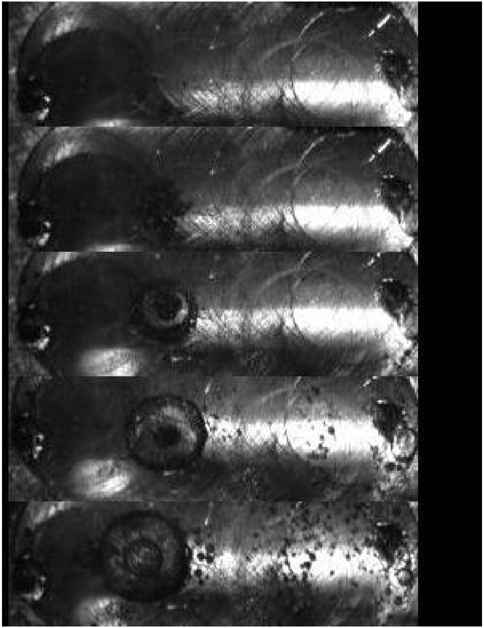
$E = 80\ \%$



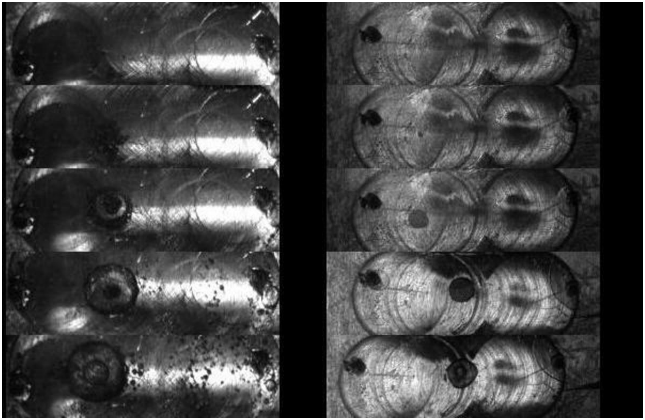
Influence of the fluid's properties

-More viscosity, smaller radius

-Less *secondary* cavitation activity

E = 5,10,20,40,80 %

Water Glycerol



$\mathbf{t=0}$ μs Water Glycerol

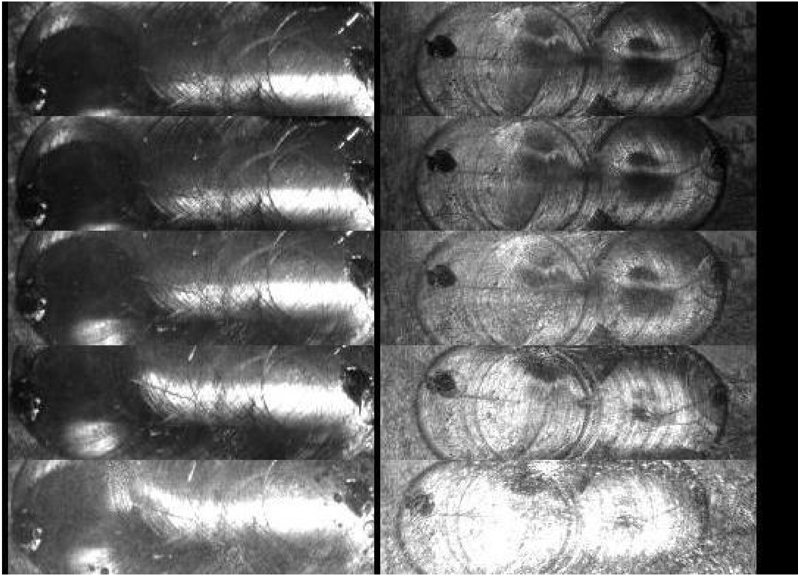
E = 5 %

E = 10 %

E = 20 %

E = 40 %

E = 80 %



t=3.3 μs Water Glycerol

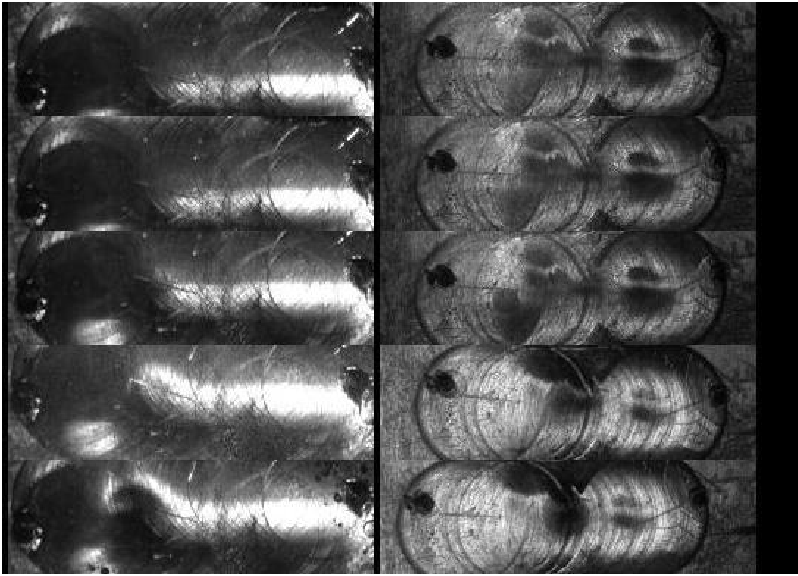
E = 5 %

E = 10 %

E = 20 %

E = 40 %

E = 80 %



t=6.6 μs Water Glycerol

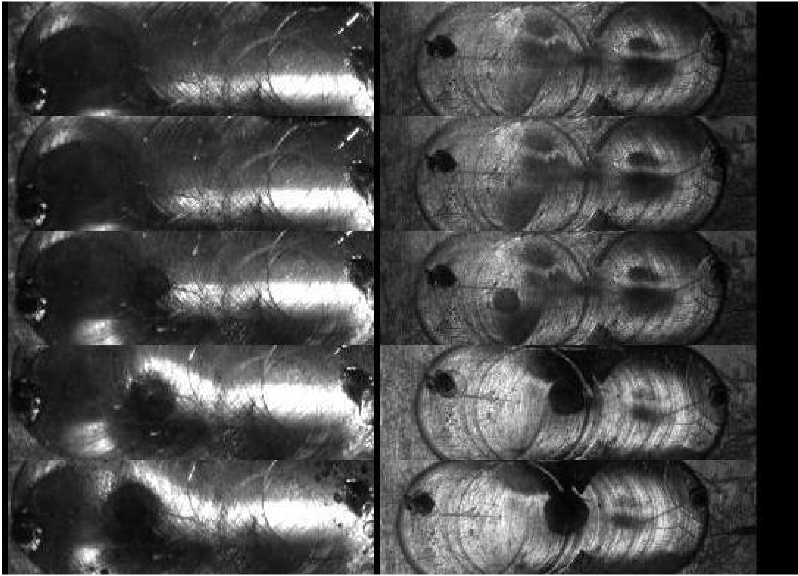
E = 5 %

E = 10 %

E = 20 %

E = 40 %

E = 80 %



Short times $t < 6.6\mu s$ Bubble Inception $E \geq 10\% E_{max}$

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Influence of fluid properties on PVDF measurements: $PDVFsignal \propto P$

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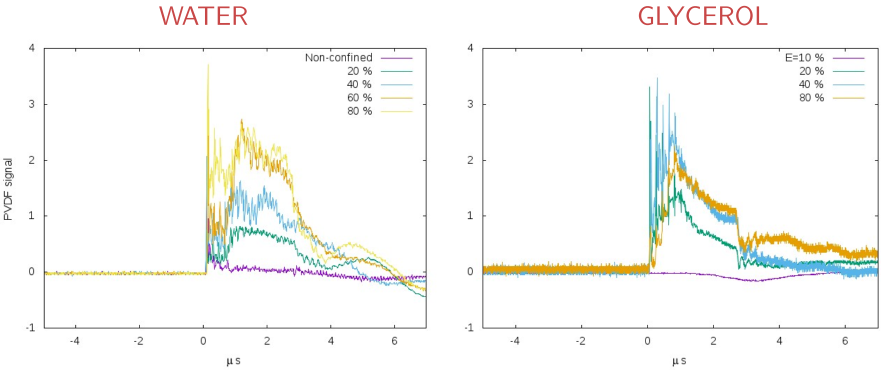
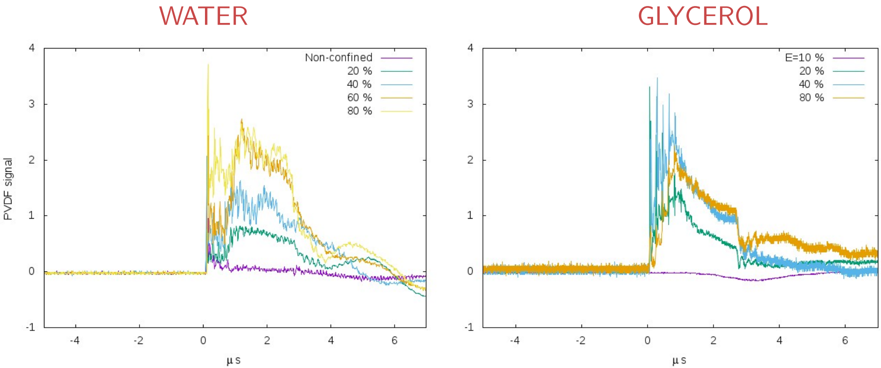


-At short times some features are common for samples with both fluids

Short times $t < 6.6\mu s$ Bubble Inception $E \geq 10\% E_{max}$

Influence of fluid properties on PVDF measurements: $PDVFsignal \propto P$



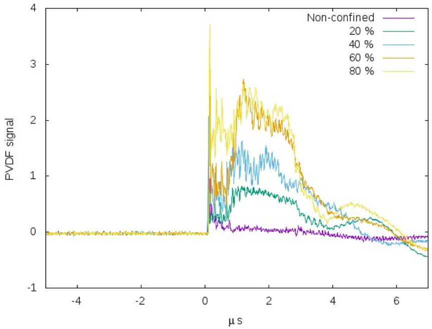
-At short times some features are common for samples with both fluids

-Signal saturates for $E > 60\%$

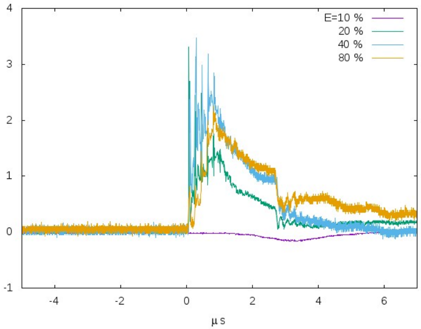
Short times $t < 6.6\mu s$ Bubble Inception $E \geq 10\% E_{max}$

Influence of fluid properties on PVDF measurements: $PDVFsignal \propto P$

WATER



GLYCEROL



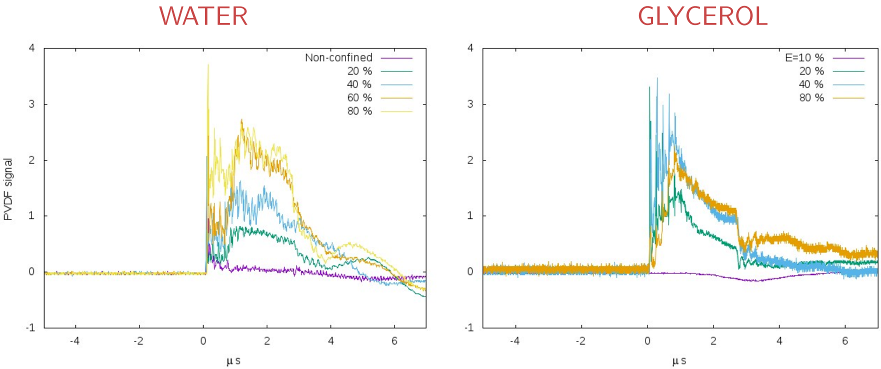
-At short times some features are common for samples with both fluids

-Signal saturates for $E > 60\%$

-Glycerol attenuates the high frequency content faster

Short times $t < 6.6\mu s$ Bubble Inception $E \geq 10\% E_{max}$

Influence of fluid properties on PVDF measurements: $PDVFsignal \propto P$



-At short times some features are common for samples with both fluids

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-Glycerol attenuates the high frequency content faster

-Unknown answer to **When does bubble nucleates?**

Can we see something externally? (e.g. back face velocity)

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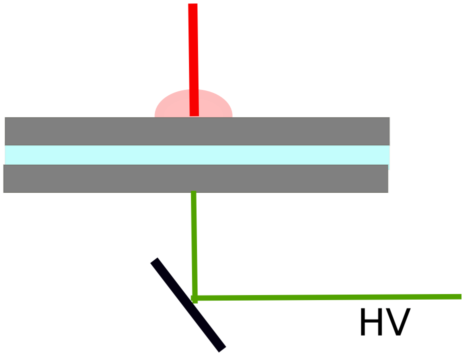
Measurement with the HV probe (or PVD: Photon Doppler Velocity)

Measurement with the VISAR (PIMM, Arts et Metiers)



We compare the two measurement techniques for Glycerol

VISAR

$V_{face} \propto P$

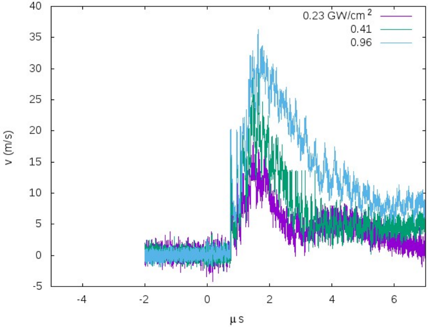
PVDF sensor

$PDVFsignal \propto P$

We compare the two measurement techniques for Glycerol

VISAR

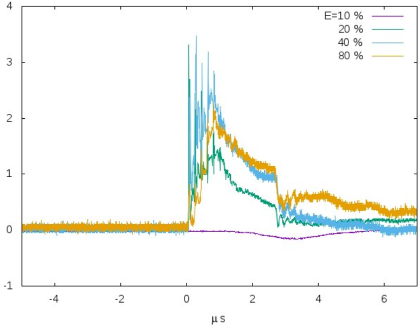
$V_{face} \propto P$



PIMM, Arts et Metiers

PVDF sensor

$PDVFsignal \propto P$



Similar qualitative measurements (also for water)

But only appropriate for extremely fast events

t=13.3 μ**s** First cav activity in bulk

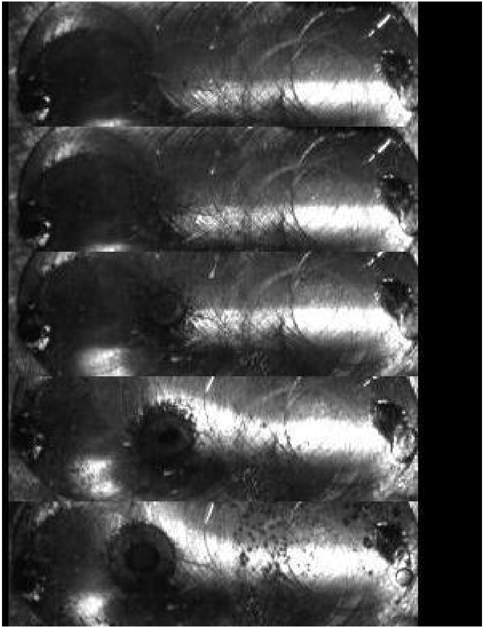
E = 5 %

E = 10 %

E = 20 %

E = 40 %

E = 80 %



t=30 μs: Max cav activity in bulk

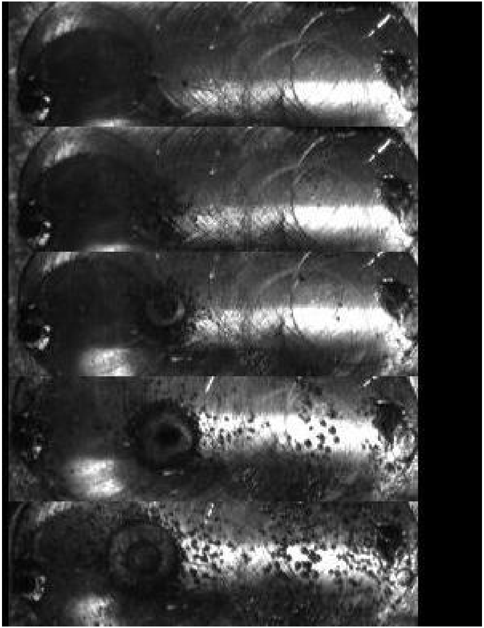
E = 5 %

E = 10 %

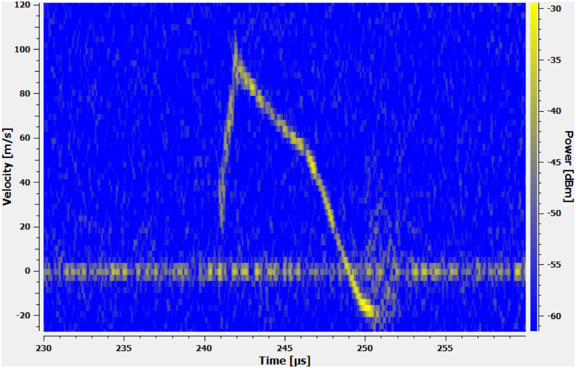
E = 20 %

E = 40 %

E = 80 %

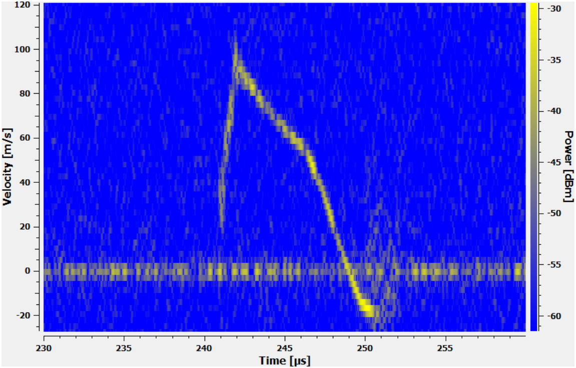


Measurement with the HV probe



-Fast dynamics at $t > 8\mu$s (after bubble inception)

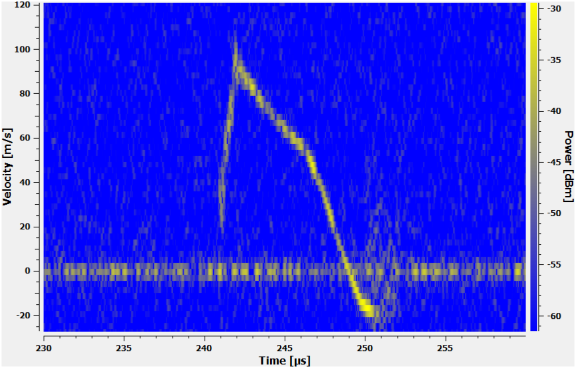
Measurement with the HV probe



-Fast dynamics at $t > 8\mu$s (after bubble inception)

-Unfortunately the HV technique does not allow to resolve such high frequencies

Measurement with the HV probe



-Fast dynamics at $t > 8\mu s$ (after bubble inception)

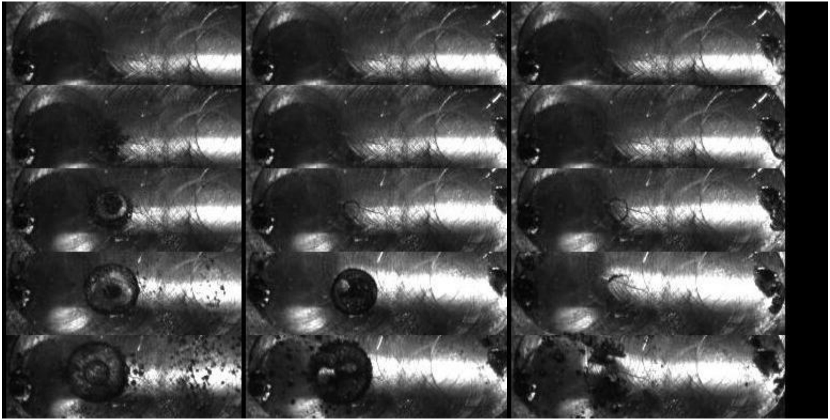
-Unfortunately the HV technique does not allow to resolve such high frequencies

-Evidence of negative velocities (e.g. tension states)

For this example $p = -170MPa$

What about longer times?

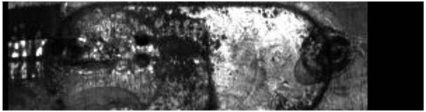
t=66 μs **t=450 μs** **t=620 μs** End of activity

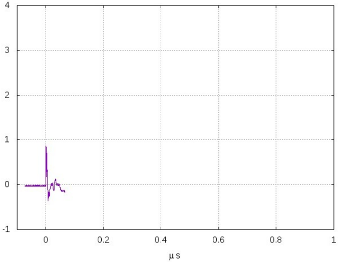


Long time evolution

Pressure fluctuations are significant while bubbles are *active*

WATER



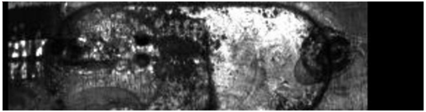


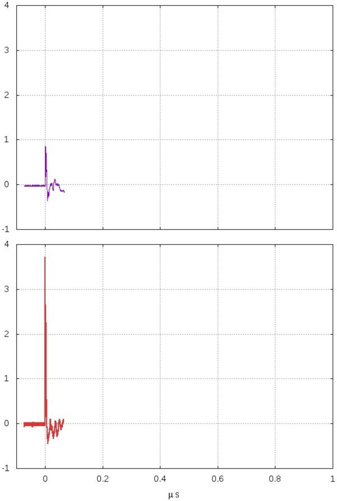
E=20%

Long time evolution

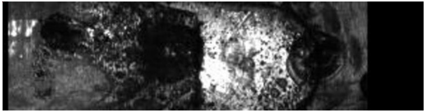
Pressure fluctuations are significant while bubbles are *active*

WATER





E=20%

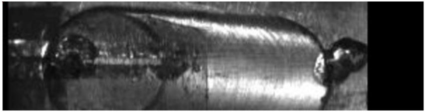


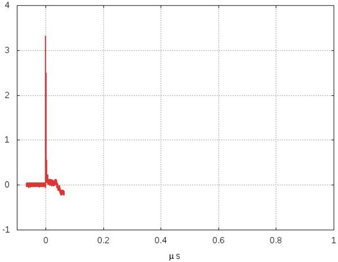
E=60%

Long time evolution

Pressure fluctuations are significant while bubbles are *active*

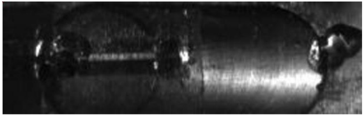
GLYCEROL

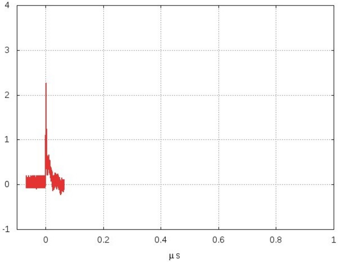




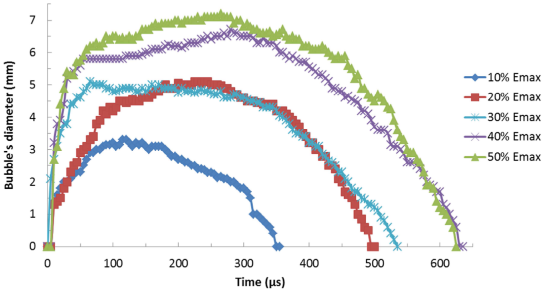
E=20%

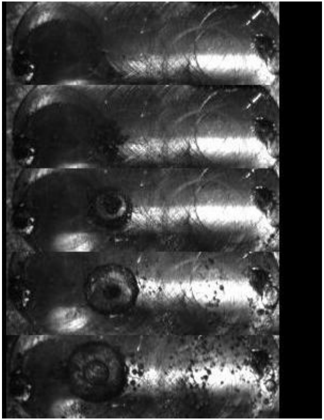
E=80%



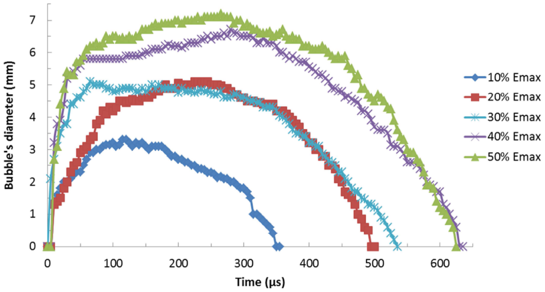


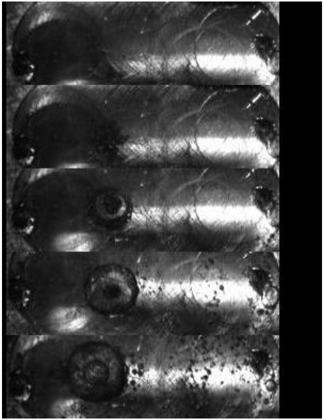
Long time evolution WATER





Long time evolution WATER



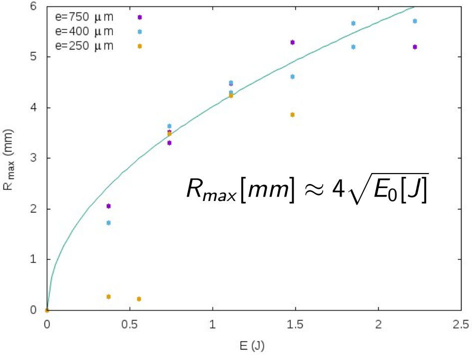


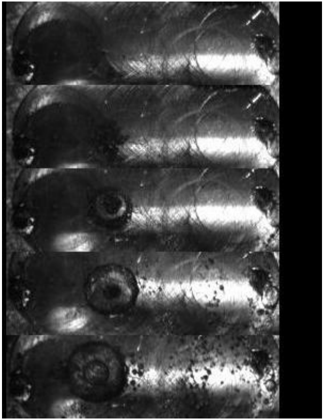
-Very fast bubble appearance $t < 20\mu s$

-Bubble expansion $20 < t < 200\mu s$

-Bubble collapse $t_{collapse} \approx 200 - 300\mu s$

Long time evolution WATER





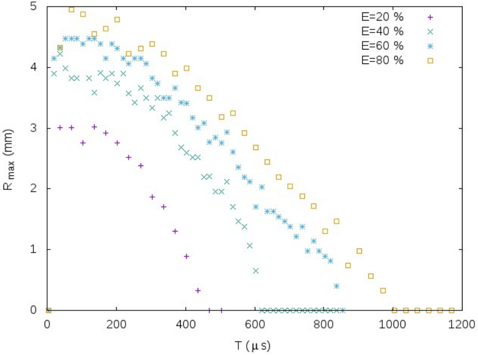
If we consider only the energy to displace the liquid:

$E = p_0 \pi R_{max}^2 e$

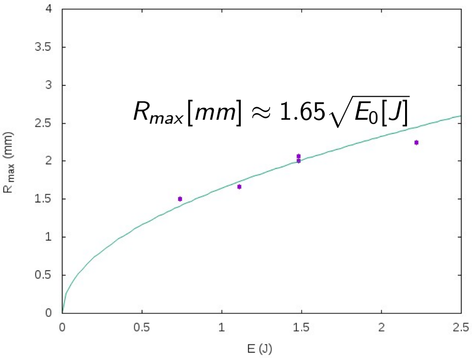
p_0: reference pressure

e: liquid thickness

Long time evolution GLYCEROL



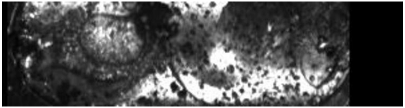
Long time evolution GLYCEROL



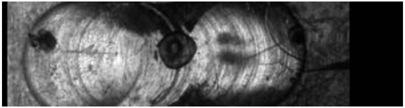
Bubble's Lifetime

Bubbles in glycerol grow less but they can last even longer than in water

E=2.25 J



WATER



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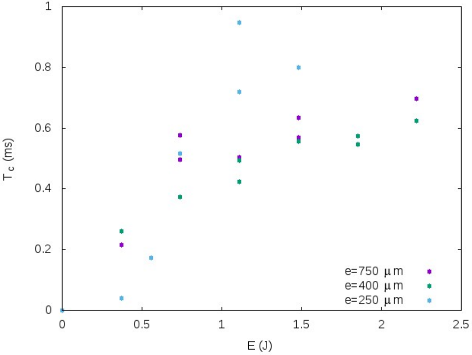
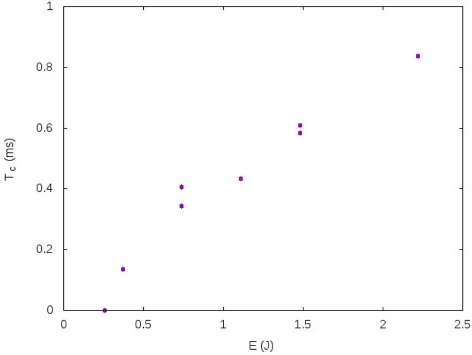
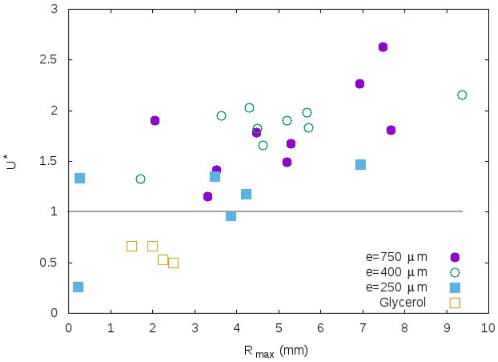




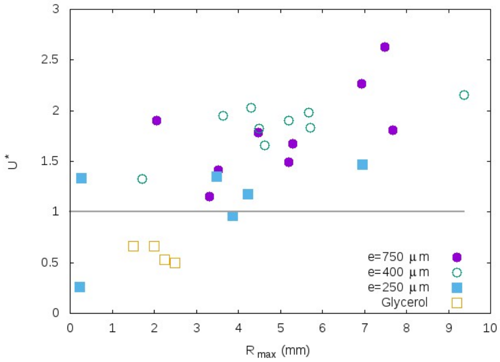
Rayleigh-like bubble collapse

$$T_c \approx R_{max}\sqrt{\frac{\rho_l}{p_0}}$$

$$U^* = \frac{R_{max}}{T_c}\sqrt{\frac{\rho_l}{p_0}}$$



Rayleigh-like bubble collapse



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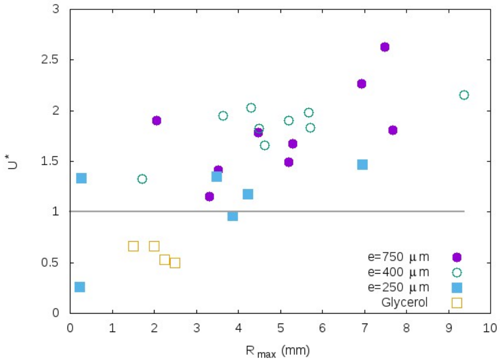

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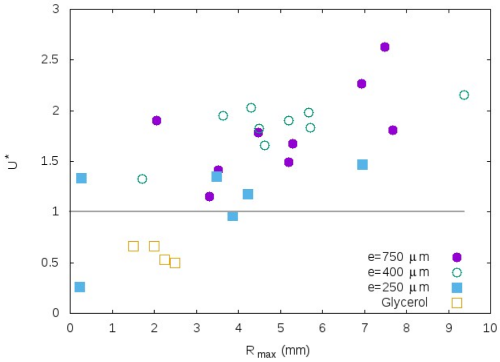

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As e decreases, the collapse time increases

Conclusions

$t < 6.6\mu s$ Bubble Inception in focal region $E \geq 10\% E_{max}$

$t \approx 10 - 30\mu s$ Cavitation inception in the bulk $E \geq 20\% E_{max}$

$t \leq 60 - 600\mu s$ Long term bubble dynamic effects

Conclusions

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Paris-Brest cake