École polytechnique universitaire de Marseille

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

UNIVERSITÉ DE PROVENCE Aix - Marseille 1

On the mutual penetrations of two gases submitted to the Richtmyer-Meshkov instability

Part 1 - experiments

Lazhar Houas, Georges Jourdan, Vincent Filpa, Guillaume Layes, Jérôme Giordano, Clément Amagat & Yves Burtschell

9th International Workshop on the Physics of Compressible Turbulent Mixing

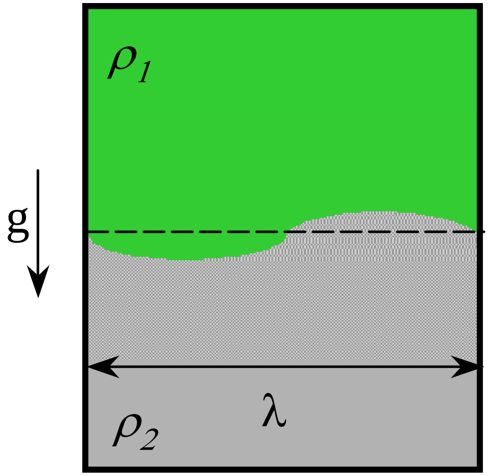
*Cambridge - **July 19-23, 2004***

Topics of discussion

- *Aim of the work*
- *Experimental description*
- *Results*
- *Summary and next step?*

Aim of the Work

Hydrodynamic instability



$$\text{Atwood} = \frac{\rho_1 - \rho_2}{\rho_1 + \rho_2}$$

g(t)=const

Rayleigh - Taylor instability

g(t)=δ(t)[u]

Richtmyer - Meshkov instability

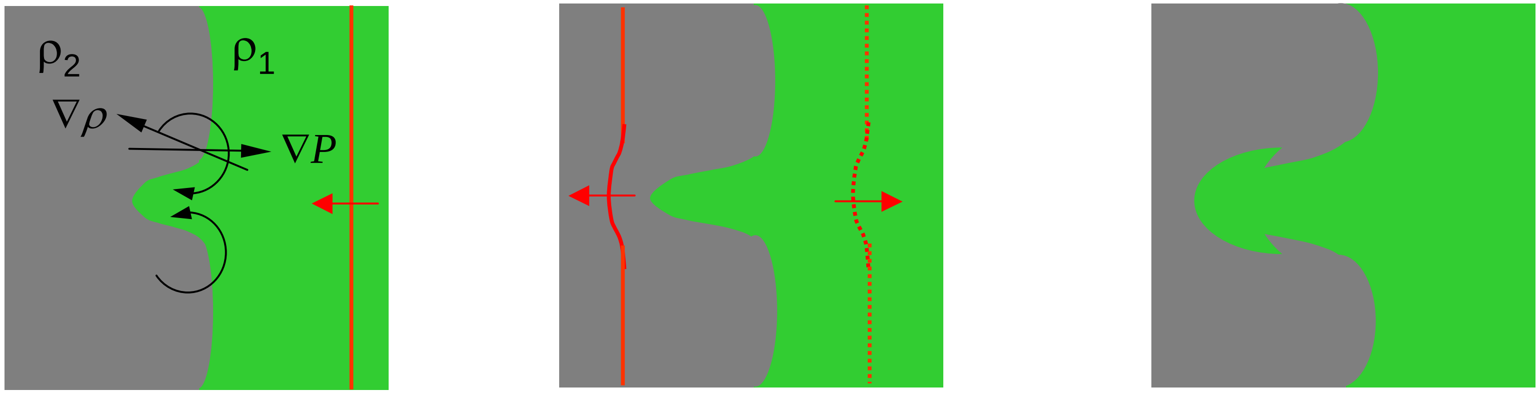
•*Application*

- *laser implosion of D - T fusion targets*
- *stellar formation due to pressure fronts*
- *supersonic and hypersonic combustion*
- *interaction of pressure wave and flame front*

The Richtmyer-Meshkov instability

- *Shock traveling from light to heavy fluid (A>0) – Direct amplication*

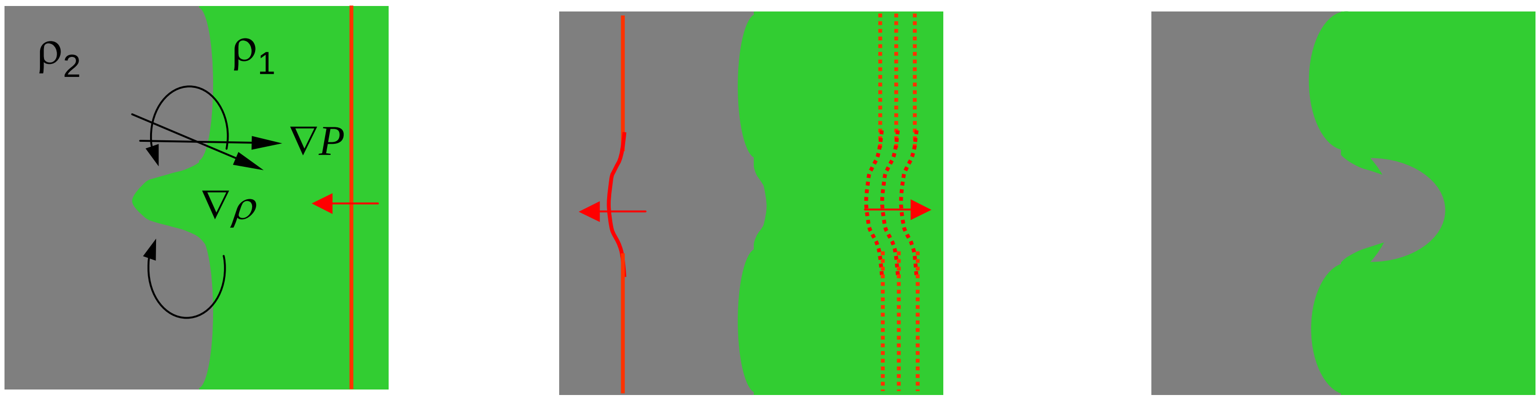
$\rho_1 < \rho_2$



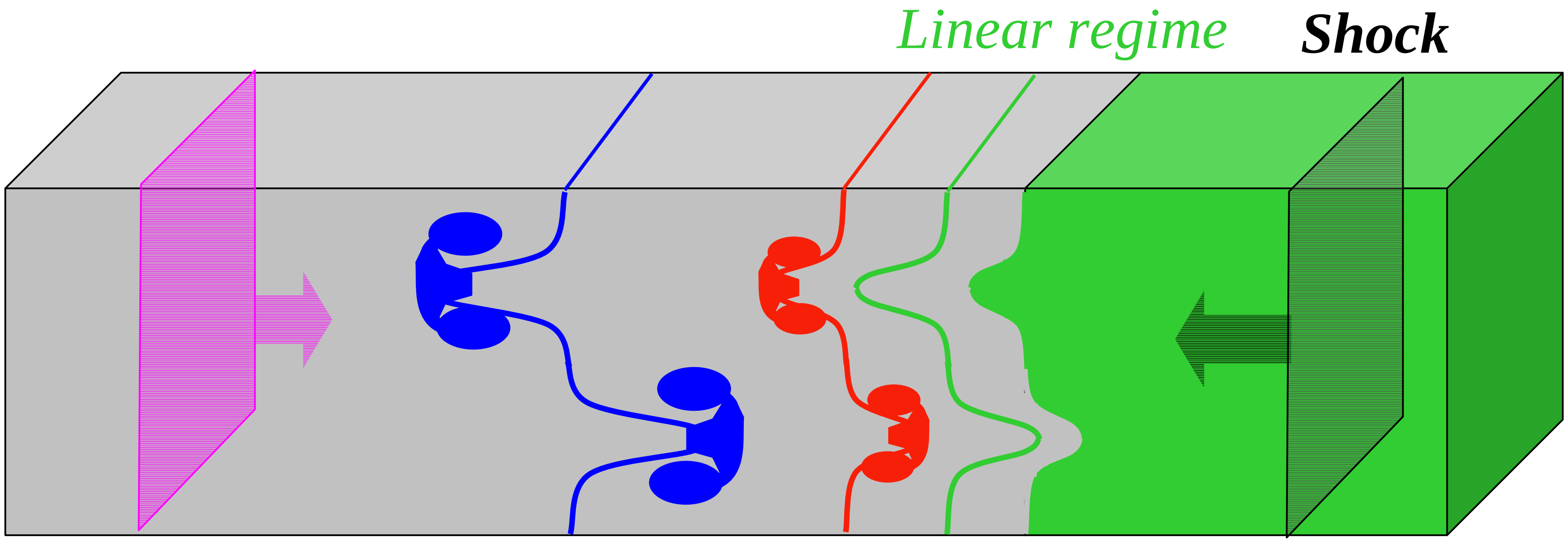
$$\vec{\nabla}\rho \times \vec{\nabla}P \neq 0 \;\Rightarrow\;$$ *Baroclinic generation of vorticity*

- *Shock traveling from heavy to light fluid (A<0) – Reversal phase*

$\rho_1 > \rho_2$



Mutual penetration:bubbles and spikes?



Transition ?

Non-linear regime ?

Inter-penetration of the fluids?

Re-shock ?

- •Positive and negative 2D large
- • amplitude perturbations

$\frac{2\pi}{\lambda}\eta_0 \sim 1$

- Heavy/light case
- Light/heavy case

-Large cross section shock tube

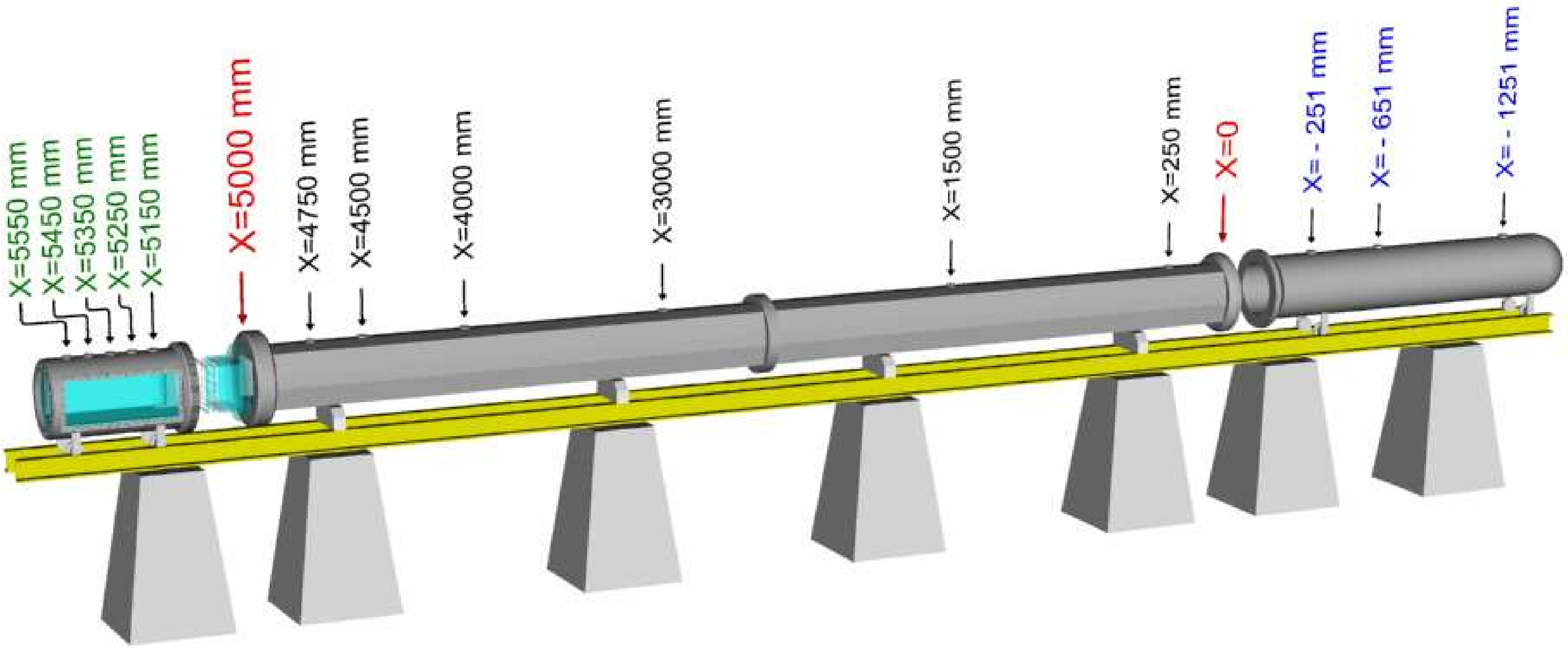
-Knowledge of initial perturbation

-

- Planar laser sheet technique

Experimental description

The shock-tube



- *Description and performances*

- *Horizontal orientation*

-Large square cross section: 200 mm

- Total length: 7 m

Driver chamber length: 1.5 m

Driven and test chamber length: 5 m + 0.5 m

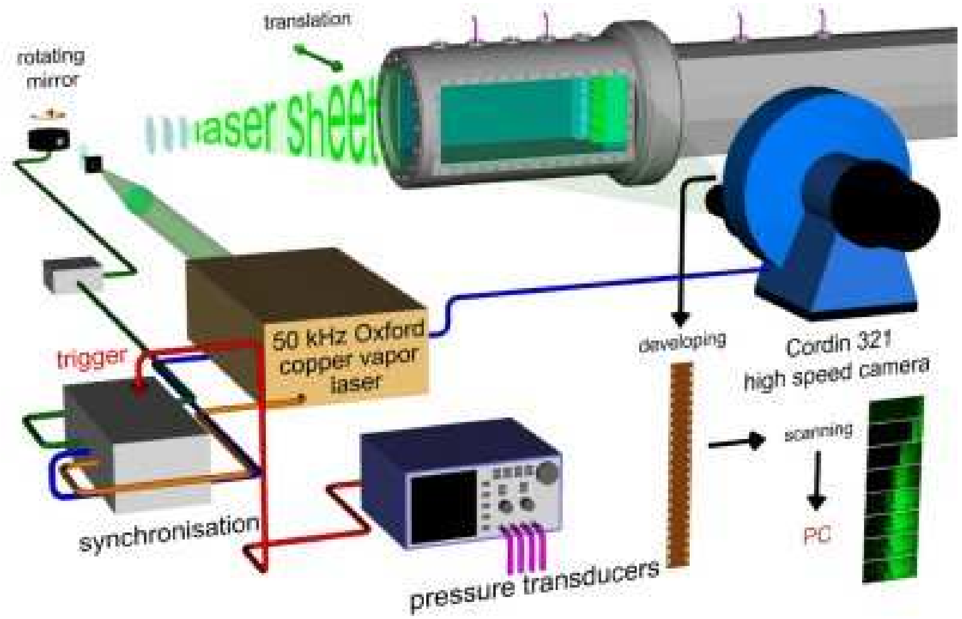
-Shock Mach number range: from 1.1 to 3

-Initial pressure: from 1 to 10^{-3} atm.

The laser sheet technique

•Laser sheet visualisation technique

- Oxford copper vapor laser
  20 watts, 50 kHz, 530 nm
-Drum camera up to100 m/s (strobodrum) to 300 m/s (cordin)
-PCB pressure gauges
- 4 channel digital scope



Planar Mie scattering

Seeding with smoke

The membrane

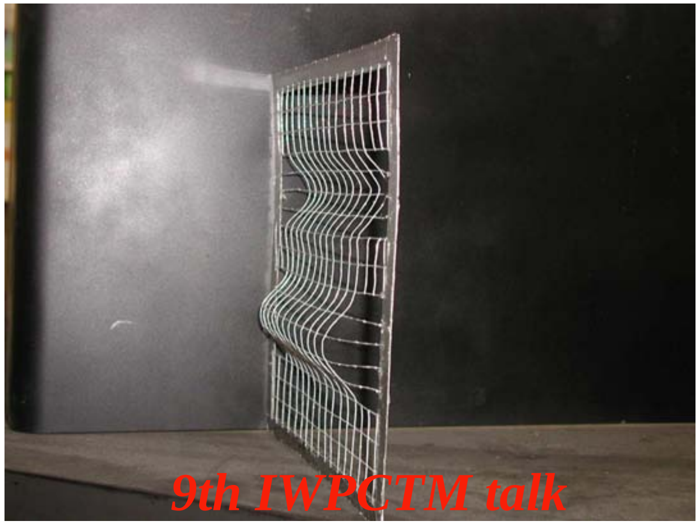
- **Nitrocellulose membrane**
  - 2 layers

    (thickness < 1 μm)

- **Membrane frame**
  - Shaped grid

    $(12.5\times12.5\ \mathrm{mm}^2)$, 0.8 mm thick

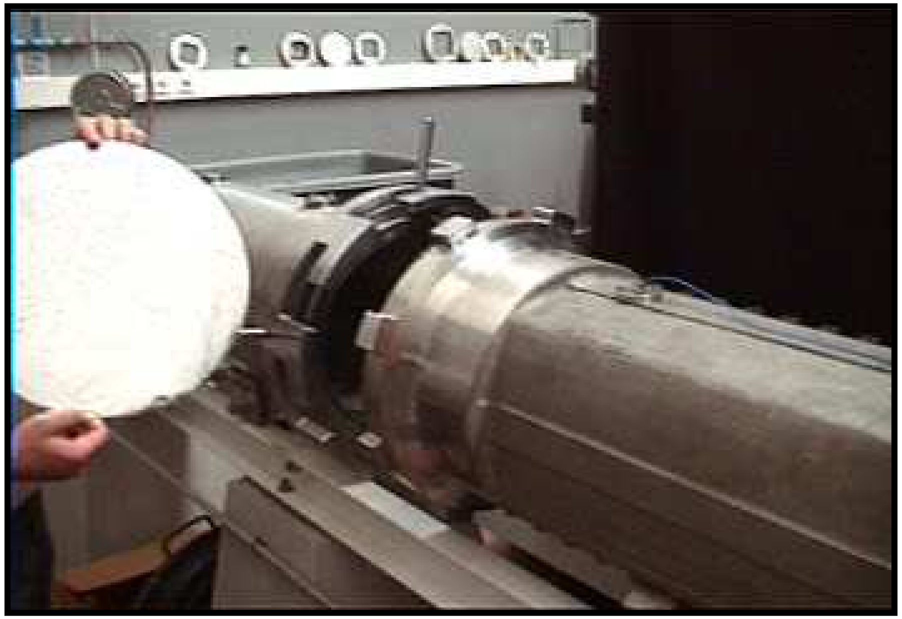
24th ISSW talk



9th IWPCTM talk

The preparation

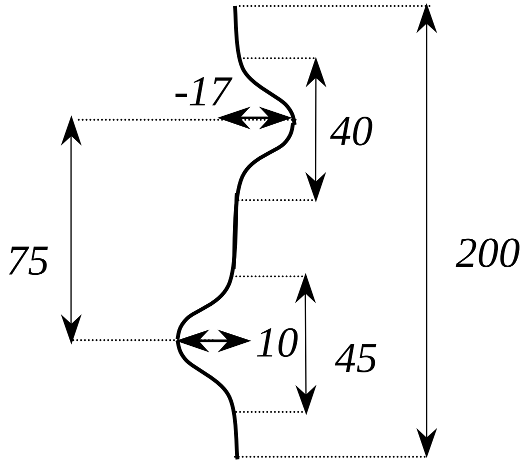
- Driver/driven chamber close
  - First diaphragm



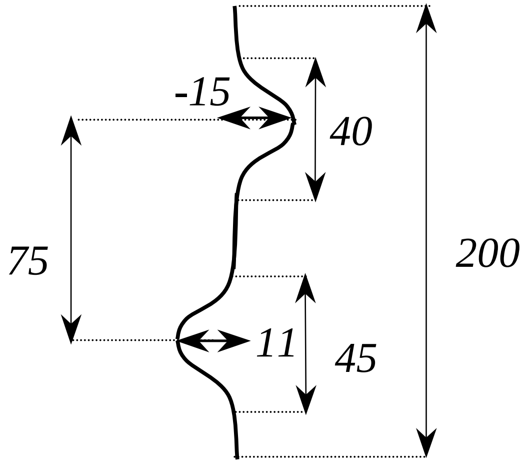
- Driven/test chamber close
  - Second diaphragm

The initial conditions

- 2D large perturbations



air/helium (H/L)



air/SF_6 (L/H)

- Heavy/light case
  - Smoked air/helium
  - Atmospheric pressure
  - Shock wave Mach number ~1.3
  - At=-0.7 and ΔU=220 m/s
- Light/heavy case
  - Smoked air/SF_6 + small leak
  - Atmospheric pressure
  - Shock wave Mach number ~1.3
  - At=+0.7 and ΔU=103 m/s

The run

- Experimental parameters
  - Laser frequency: 10 kHz (1 frame per 100 μs)
  -Camera speed: 80 m/s
  - Time seeding: 10 mn
  -Time gas circulation: 7 mn

- Laser shot runnig
  - 10 kHz normal running
  -Trigger
  -10 ms stop (diaphragm opening)
  -100 flashes at 10 kHz
  -500 ms stop (diaphragm closing)
  -10 kHz normal running

Results

Heavy/light (air/He) visualization

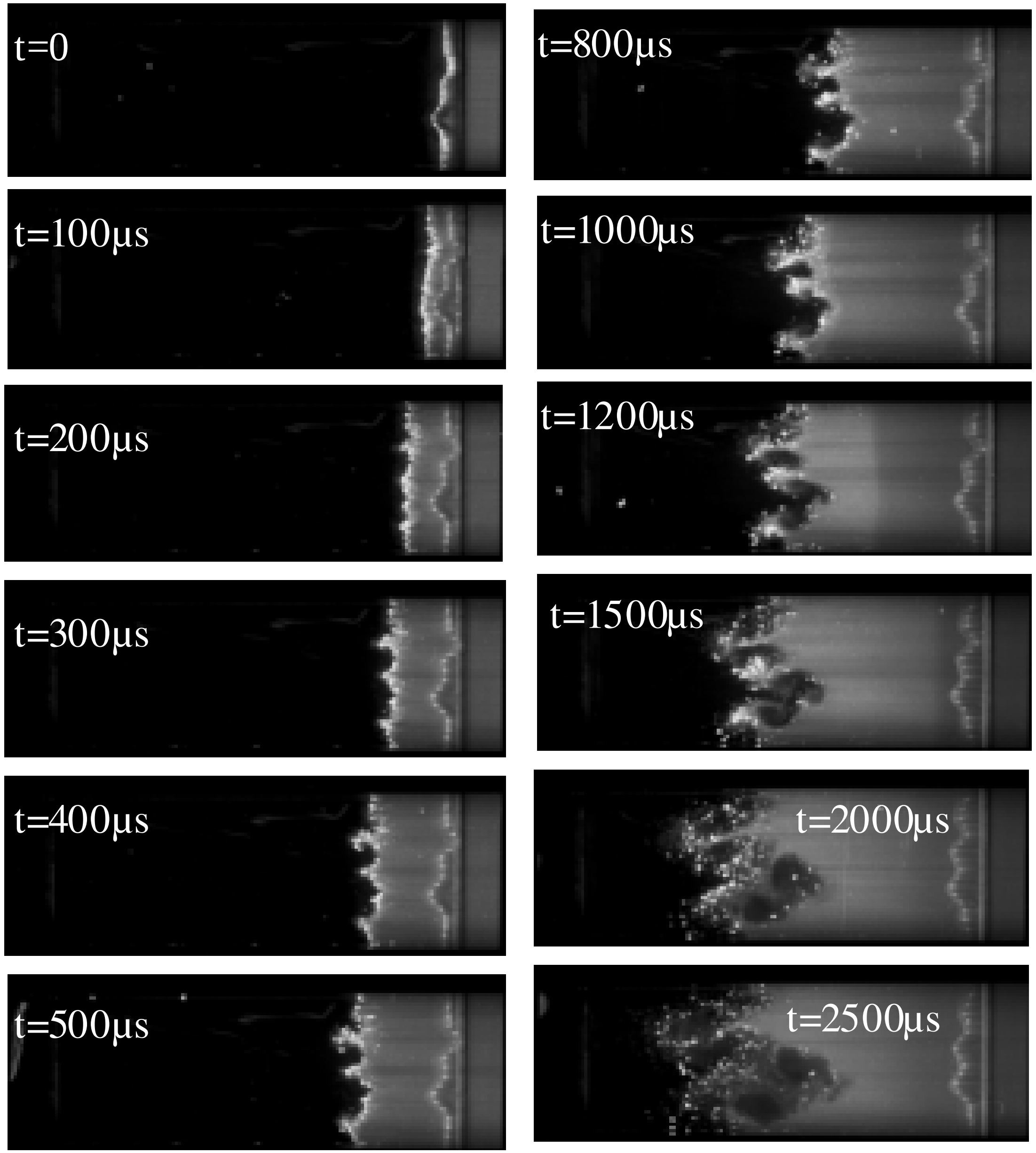
Helium

Air seeded with smoke

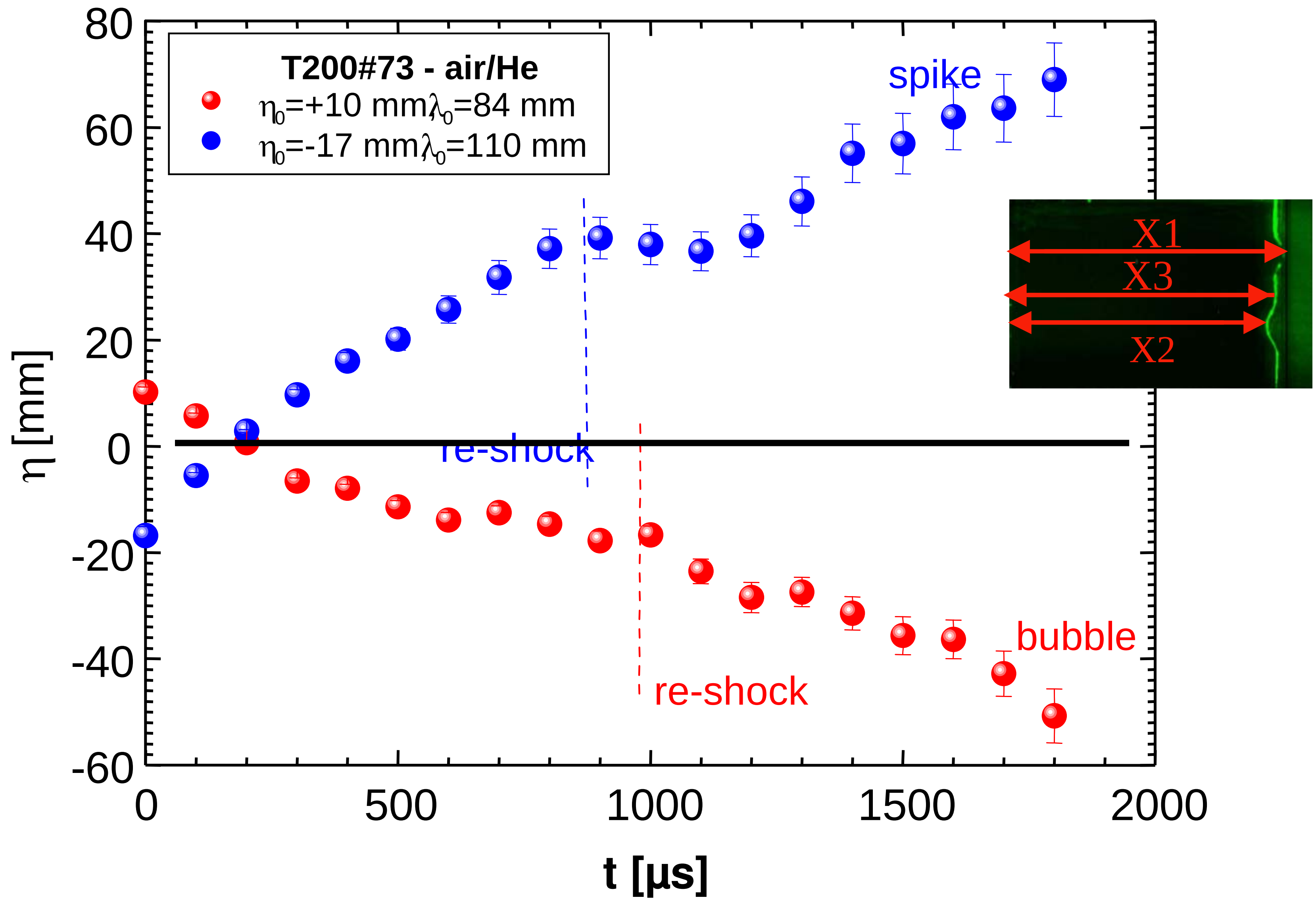
M_{is}=1.3

P_{init}=1 atm., A_{post}=-0.7 - Reversal phase

Heavy/light (air/He) visualization

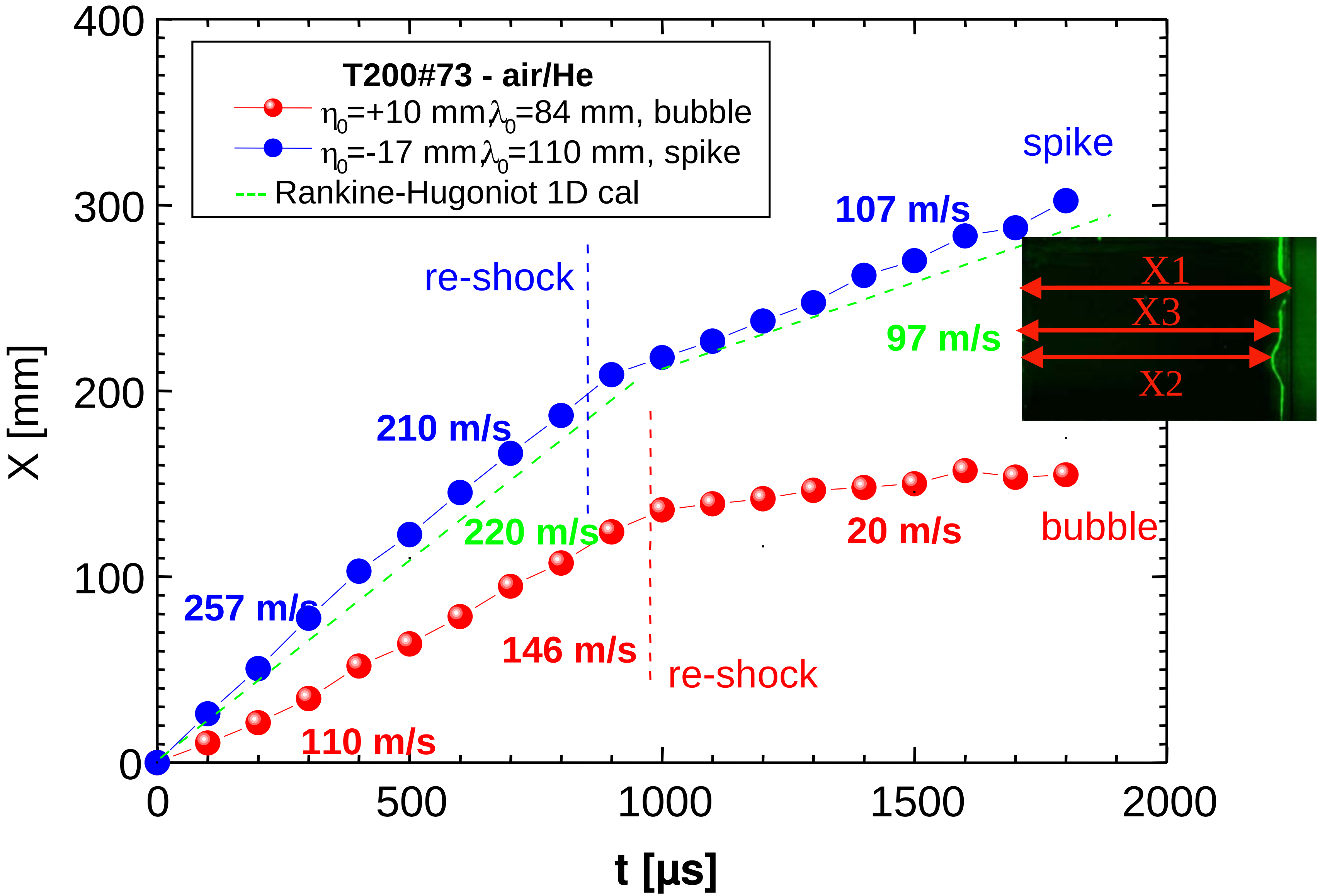


Heavy/light results (air/He)



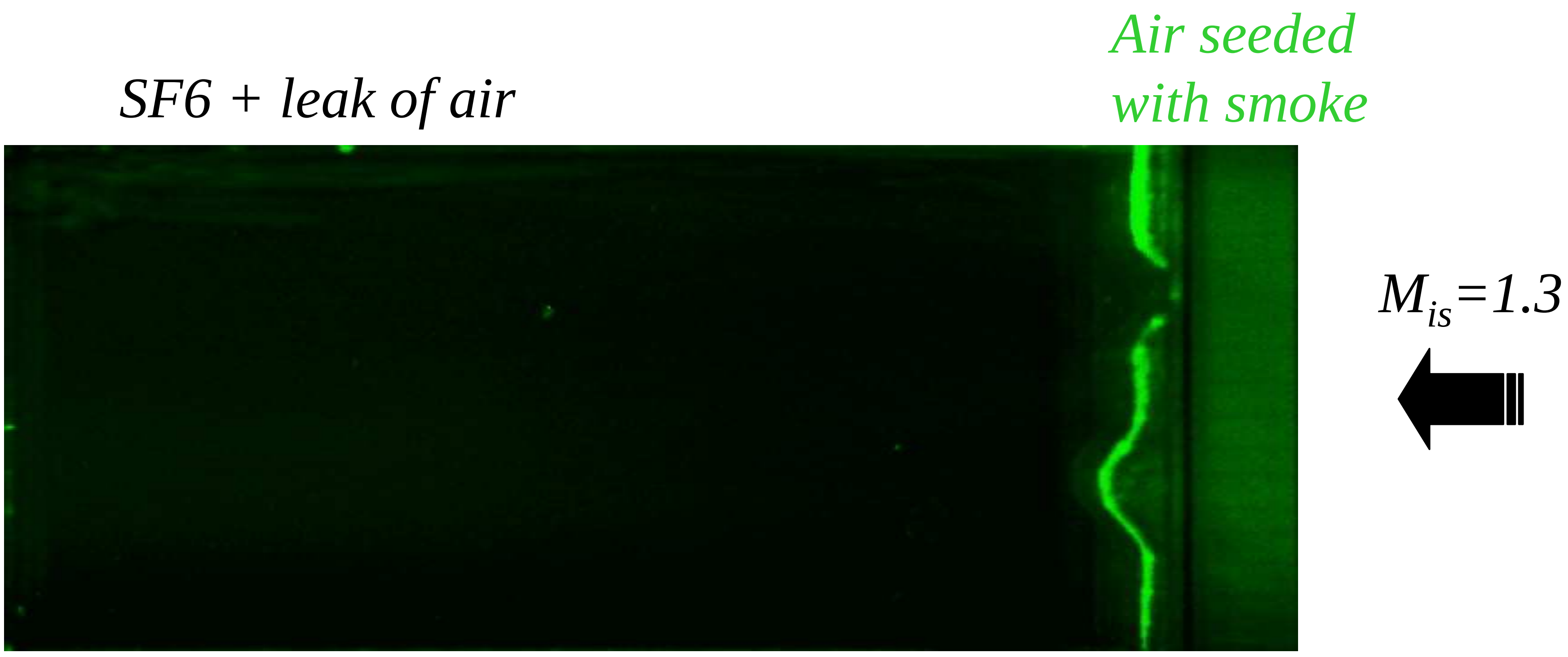
Peak to peak perturbation amplitude measurements

air/He bubble and spike displacements



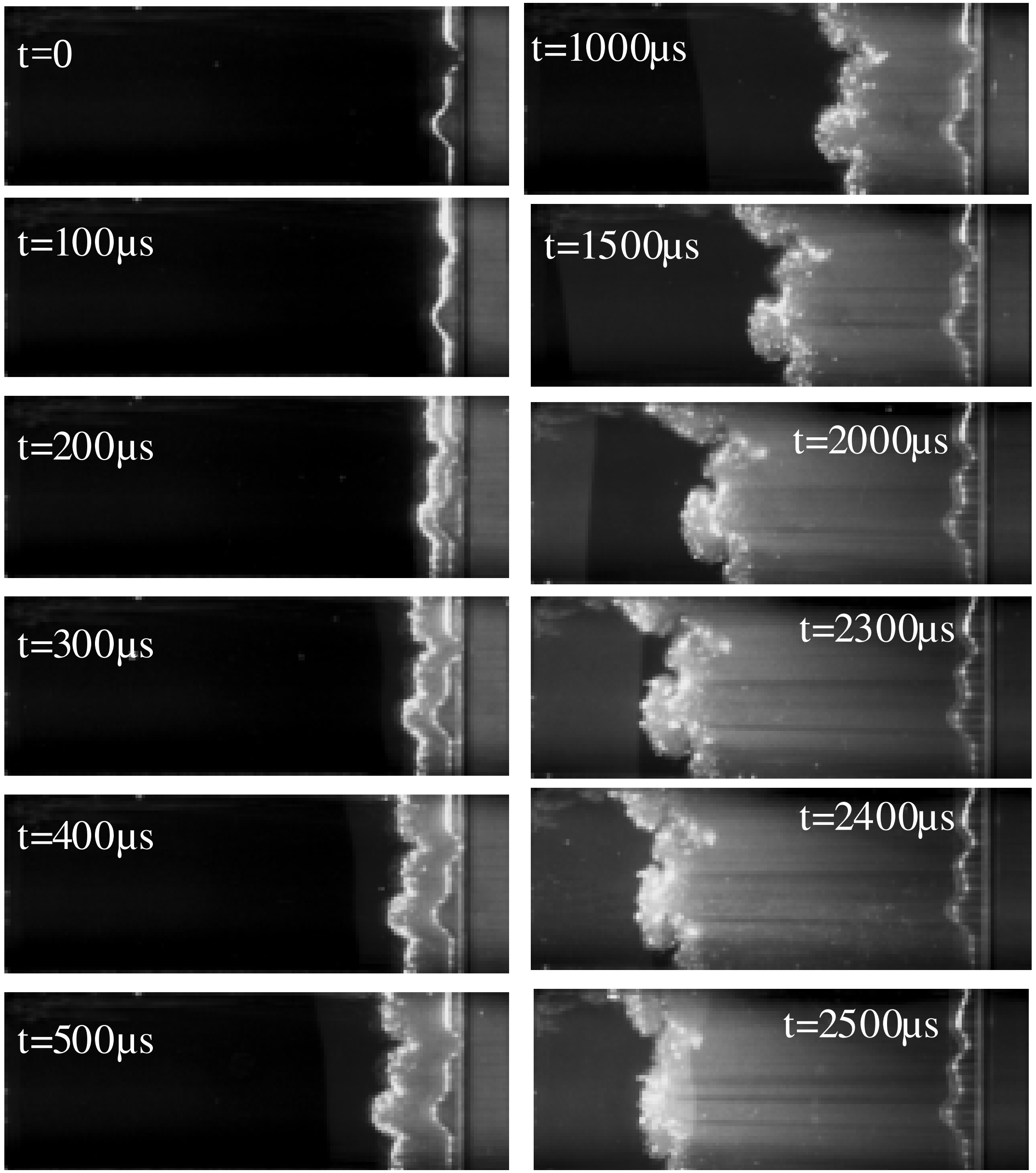
Crest and hollow displacements of the interface from their initial position

Light/heavy (air/SF6) visualization

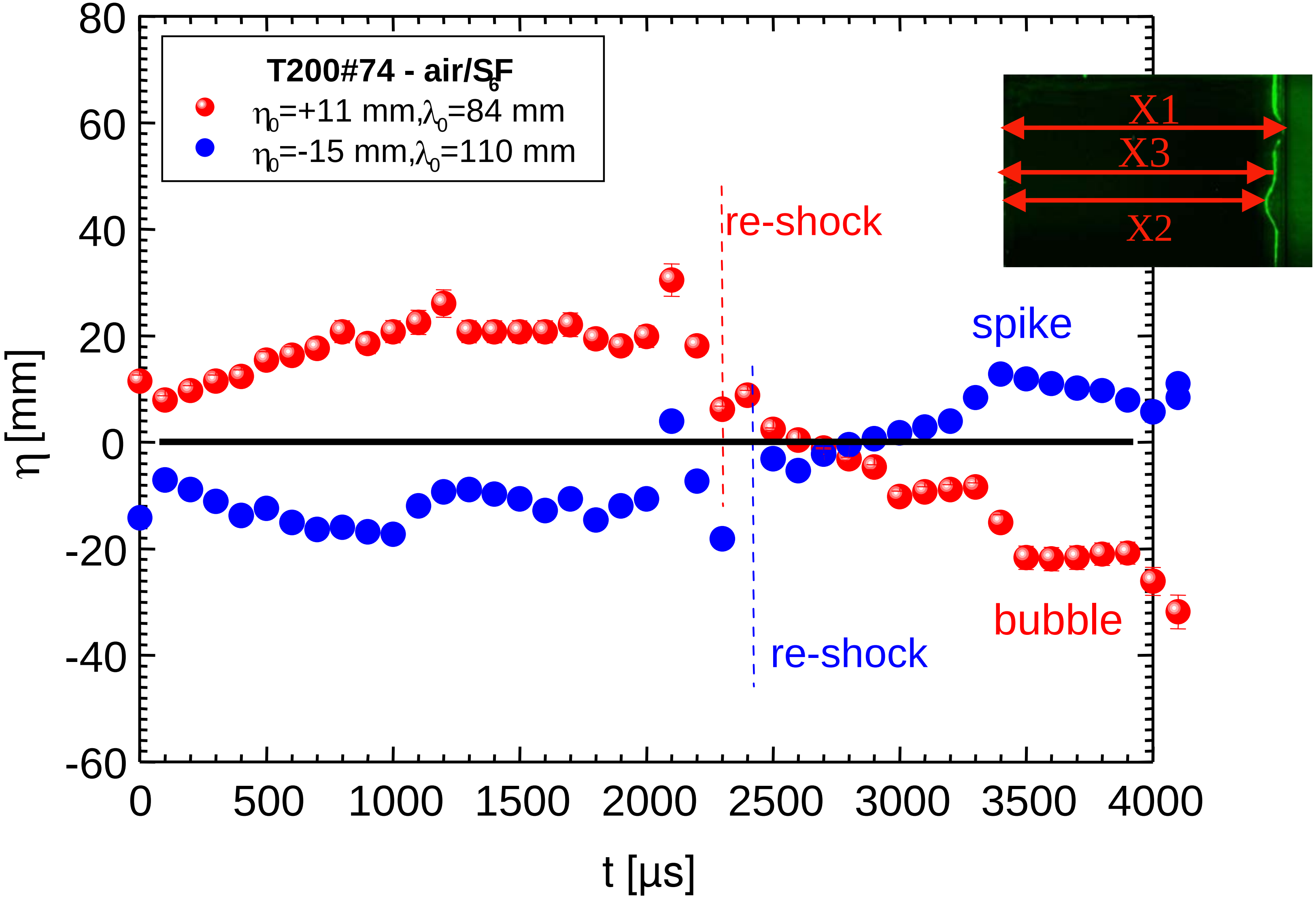


P_{init}=1 atm., A_{post}=+0.7 - No reversal phase

Light/heavy (air/SF6) visualization

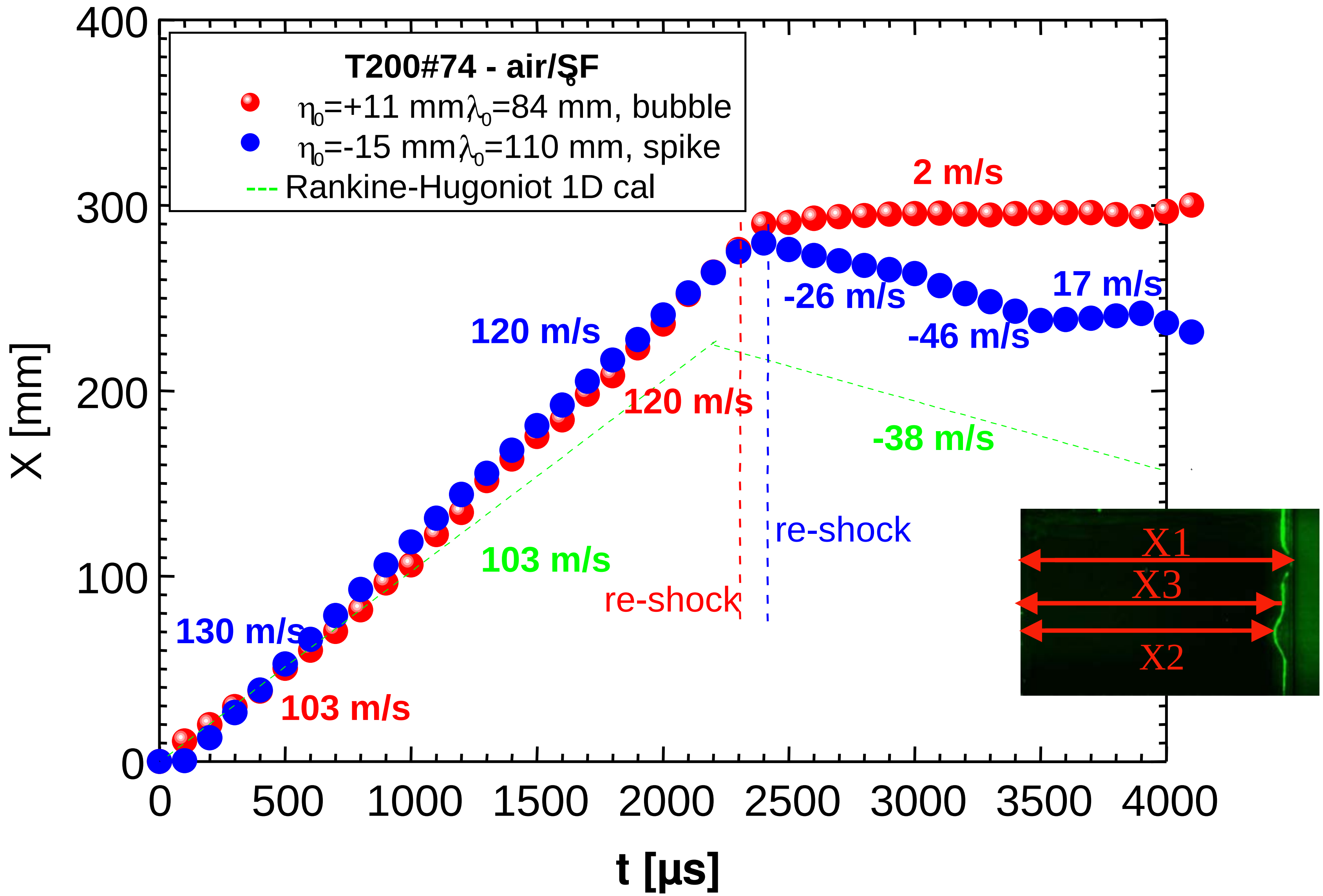


Light/heavy results (air/SF6)



Peak to peak perturbation amplitude measurements

air/SF6 bubble and spike displacements



Crest and hollow displacements of the interface from their initial position

Growth rate analytic theories

- Richtmyer (1960) impulsive model

$$\eta(t) = kU_{rm} A \eta_0 t$$

-Alon et al. (1995) non-linear theory

$$\eta(t) = \eta_0 t^{\theta}$$

-Zhang & Sohn (1997) non-linear theory

$$\left(\frac{d\eta(t)}{dt}\right)_{zhang} = \frac{\left(\frac{d\eta(t)}{dt}\right)_{RM}}{1 + \left(\frac{d\eta(t)}{dt}\right)_{RM} \eta_0 k^2 t + max\left[0, \eta_0^2 k^2 - A^2 + \frac{1}{2}\right]\left(\frac{d\eta(t)}{dt}\right)_{RM}^2 k^2 t^2}$$

-Sadot et al. (1998) non-linear theory

$$\left(\frac{d\eta(t)}{dt}\right)_{Sadot} = \left(\frac{d\eta(t)}{dt}\right)_{RM} \left(\frac{1+Bt}{1+Dt+Et^2}\right)$$

$$D_b = (1+A)\left(\frac{d\eta(t)}{dt}\right)_{RM} k$$

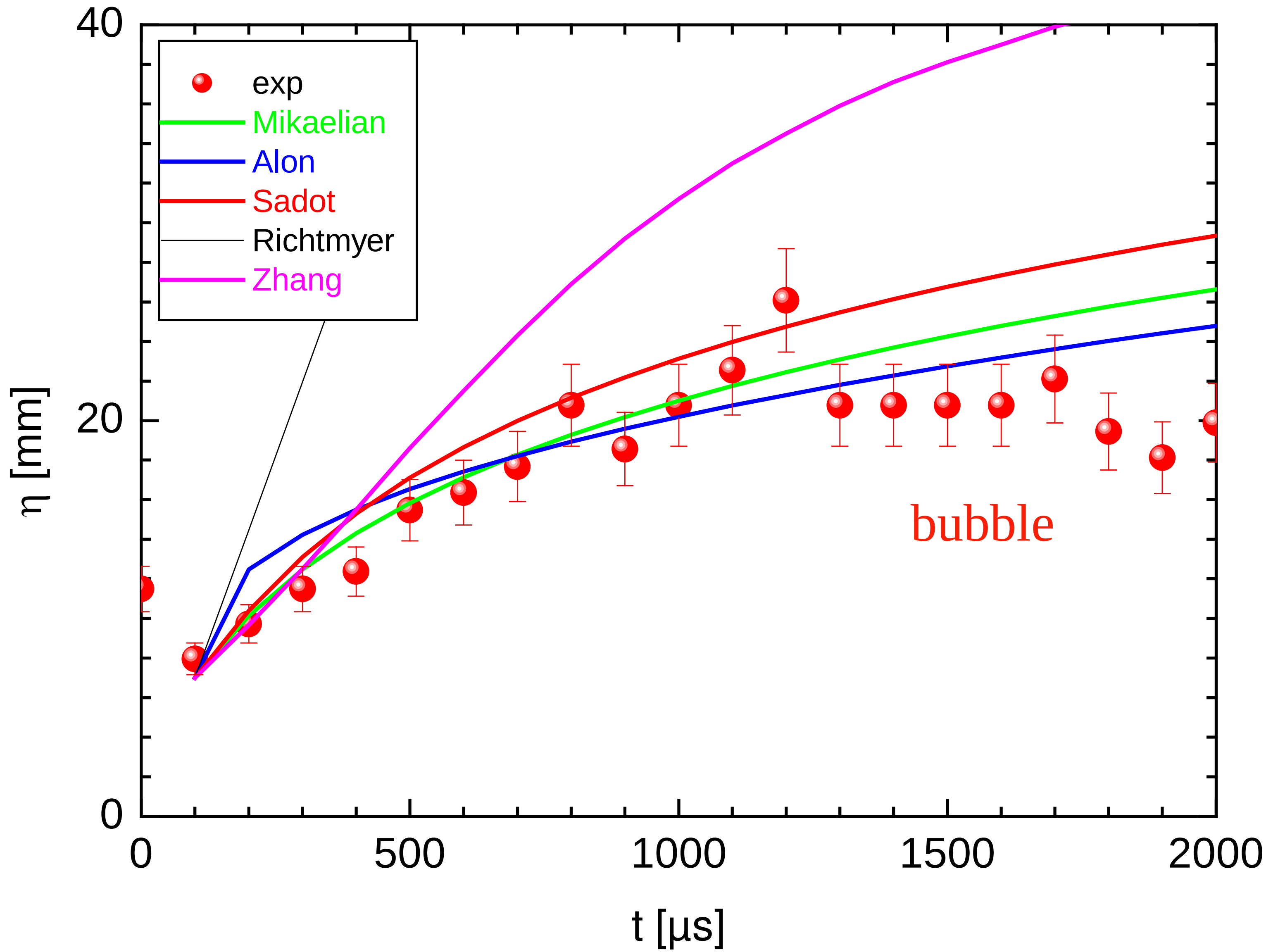
$$E_b = \left(\frac{1}{2\pi C}\right)\left(\frac{d\eta(t)}{dt}\right)_{RM}^2 k^2$$

$$C = \frac{1}{3\pi} \quad \text{pour } A > 0.5$$

-Mikaelian (1998) non-linear theory

$$\eta(t)k = \eta_0 k + \frac{2}{3}\ln\left(1 + \frac{3}{2}kt\left(\frac{d\eta(t)}{dt}\right)_{RM}\right)$$

air/SF6 perturbation amplitude



Comparison of peak-to-peak perturbation amplitude measurements with theories

Summary and next step

Summary

- *An investigation of shock induced gas mixing*
  - *Large cross section shock tube*
  - *Large 2D positive and negative perturbations*
  - *Heavy/Light and Light/Heavy cases*
  - *laser sheet technique*
- *In the present experiments we have got better accuracy for bubble measurements than for spike*
- *Strong asymetric mutal penetration for the Heavy/Light case and less pronouced for the Light/Heavy one*
- *Spike moves very faster than bubble in the Heavy/Light case and slightly faster than bubble in the Light/Heavy one*
- *Agreement with existing theories*
  - *Light/Heavy (air/SF6) bubble case*

Needed improvements

Next step

- Different perturbations
  - Change shapes, amplitudes and wave lengths
- Increase the laser frequency up to 50 kHz
- Increase the shock wave Mach number
  - M~3
  - P~0.5 atm.
- Delay the return of the reflected shock wave in order to increase the time observation
  - Lengthen the test chamber
- Reduce the membrane effects
  - Burn the membrane before the shock interaction