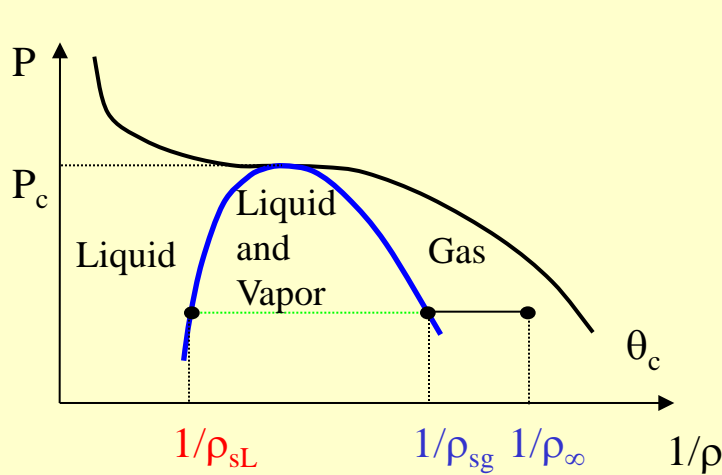


Supercritical vaporization process

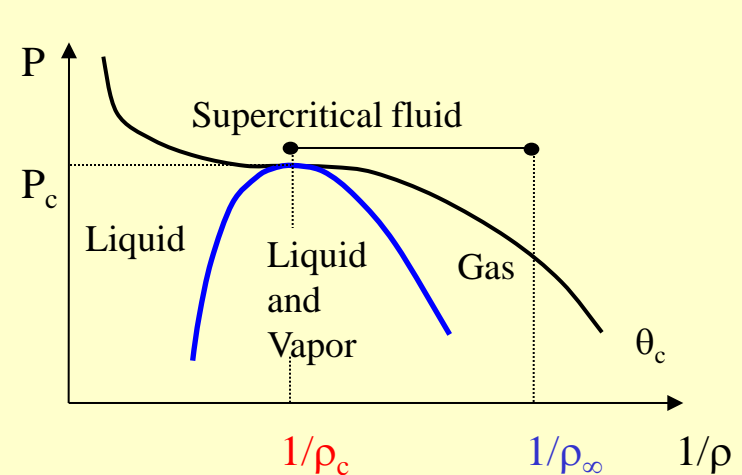
Stéphane Préau, Roger Prud'homme, Renée Gatignol
(LMM-Paris)

Configuration

Subcritical vaporization



Supercritical vaporization



Quasi-Steady vaporization

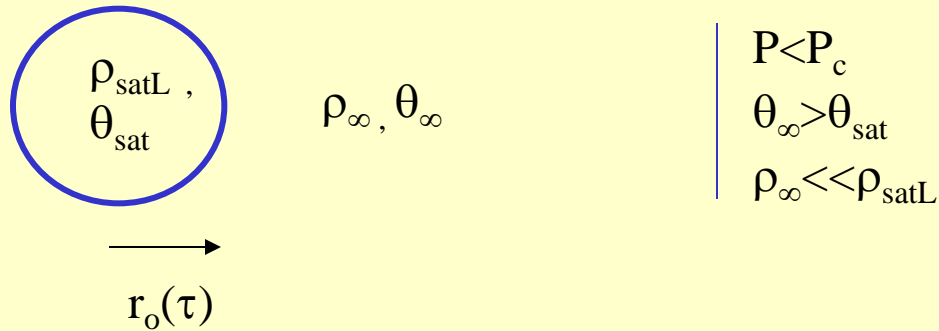
$$\varepsilon = \frac{\rho_{\infty}}{\rho_c} \ll 1$$

Scheme

- I) Subcritical droplet vaporization
- II) Supercritical droplet vaporization
- III) Conclusions, prospects

I) Subcritical droplet vaporization

Initial conditions



Liquid A \Rightarrow Gas A

Assumptions

- ★ Isobaric process
- ★ $\gamma_{\infty} = \frac{t_{\text{gas diffusion } \infty}}{t_{\text{life time}}} \ll 1$

Quasi-Steady expansions

$$\star \quad \varepsilon = \frac{\rho_\infty}{\rho_c} \quad m(\theta) = \int_{\theta_c}^{\theta_\infty} \frac{\lambda}{\theta} \frac{d\theta'}{\int_{\theta_c}^{\theta'} C_p d\theta'' + L}$$

$$\star \quad x = r - r_o \quad \tau = \frac{t}{\text{life time}} \quad u = v - \frac{\gamma_\infty}{\varepsilon} r \dot{d}$$

$$\star \quad \cancel{\gamma_\infty \frac{\partial \rho}{\partial \tau}} + \cancel{\gamma_\infty \frac{2\rho \dot{r}_o}{(x+r_o)}} + \frac{1}{(x+r_o)^2} \frac{\partial (x+r_o)^2 \rho u}{\partial x} = 0 \quad (\text{Mass balance})$$

$$\cancel{\gamma_\infty \frac{\partial \theta}{\partial \tau}} + u \frac{\partial \theta}{\partial x} = \frac{1}{\rho C_p (x+r_o)^2} \frac{\partial}{\partial x} \left(\lambda (x+r_o)^2 \frac{\partial \theta}{\partial x} \right) \quad (\text{Energy balance})$$

\star Energy and mass flux at $r = r_o(\tau)$ (corresponding to $x=0$)

Results

$$\star \quad \theta = \theta \left(\frac{r}{r_o(\tau)} \right)$$

$$\star \quad \gamma_{\infty} = \frac{t_{diff}^{\infty}}{t_{lifetime}} = 2\varepsilon m(\theta_{sat})$$

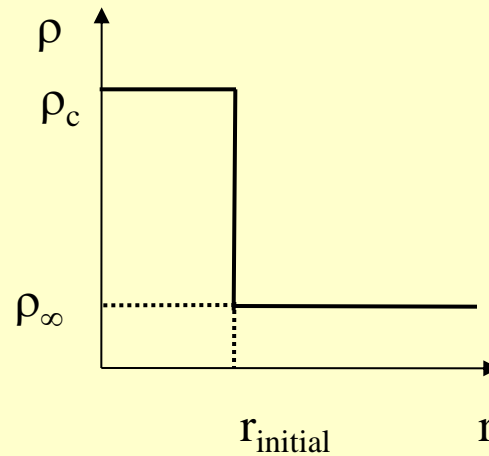
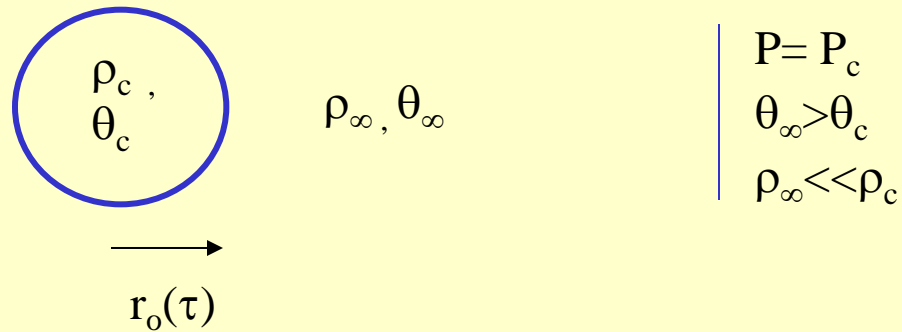
$t_{lifetime}$ is calculated

$\gamma_{\infty} \ll 1$ for $\varepsilon \ll 1$

$$\star \quad r_o^2 = 1 - \tau \quad (\text{d}^2 \text{ law})$$

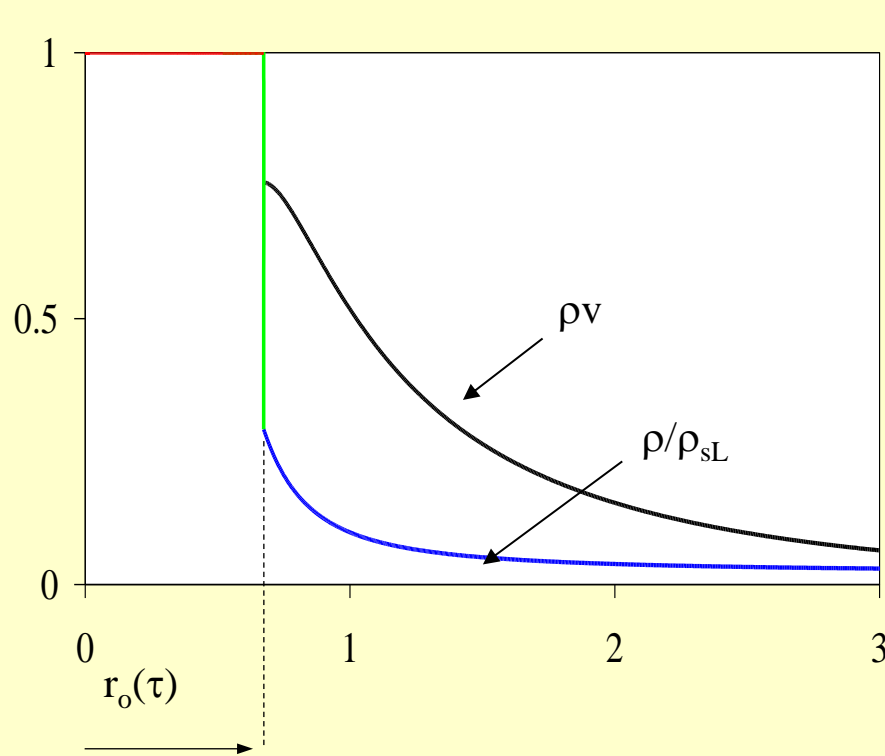
II) Supercritical droplet vaporization

Initial conditions

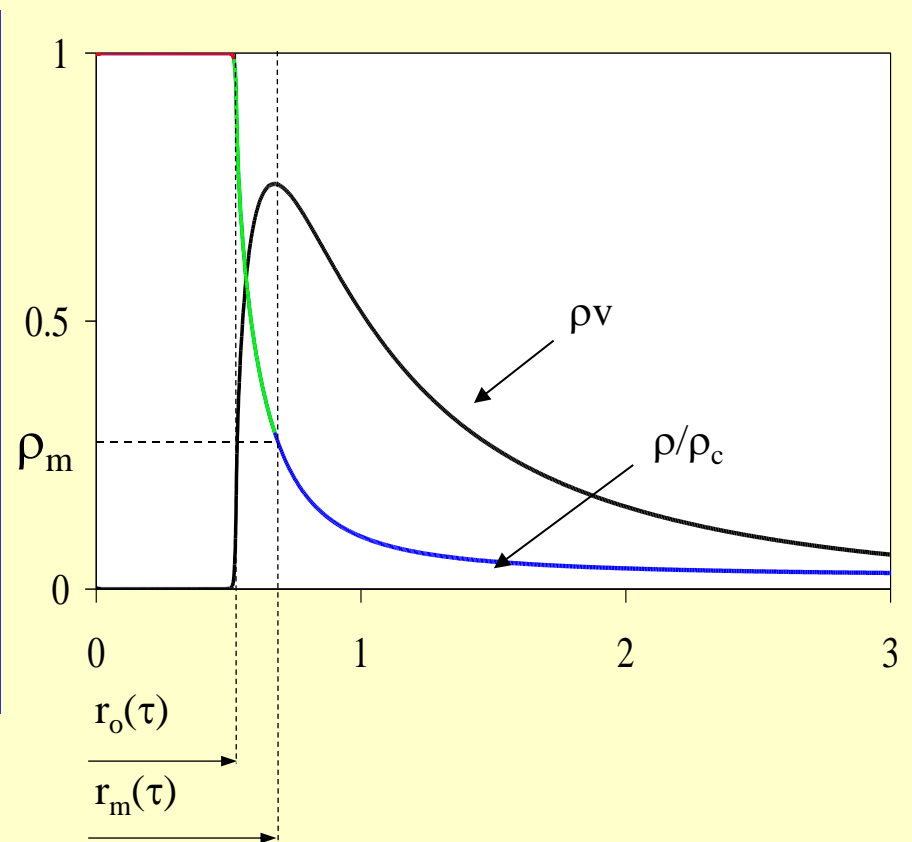


Structure

★ Subcritical vaporization



★ Supercritical vaporization



Determination of ρ_m

- ★ Asymptotic analysis : ρv is maximum at the end of the high gradient zone, around the isochore ρ_m , which bounds a domain of radius $r_m(\tau)$. Isochore ρ_m is so that :

$$\frac{t_{diff}(\rho_m)}{t_{lifetime}} = O(1)$$

Analysis in the thick “interface”

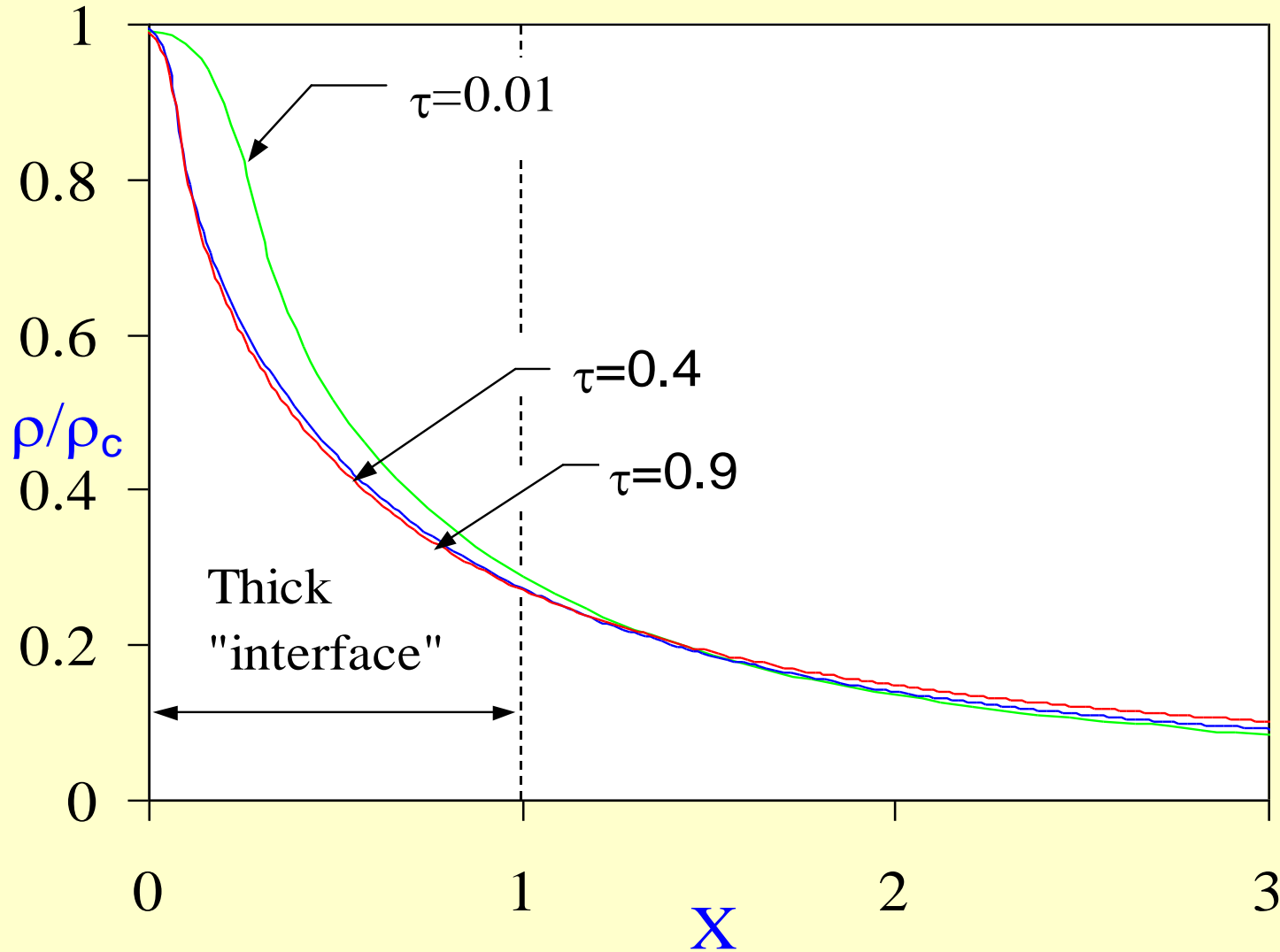
- ★ High gradient zone study: $r_o(\tau) < r < r_m(\tau)$

$$X = \frac{r - r_o(\tau)}{\delta(\tau)}, \quad \delta(\tau) = r_m(\tau) - r_o(\tau)$$

- ★ Assumption : $\delta(\tau) \ll 1 \Rightarrow$ steady situation in the (X, τ) frame

$$\Rightarrow \dot{r}_o (r_m - r_o) = - \frac{\varepsilon}{\gamma_\infty} [m(\theta_c) - m(\theta_m)]$$

$$\Rightarrow \text{Mass and energy flux in } r_m(\tau)$$



$r > r_m(\tau)$: subcritical like Quasi-Steady study

★ Quasi-Steady integration of balance equations with $\gamma_\infty \ll 1$

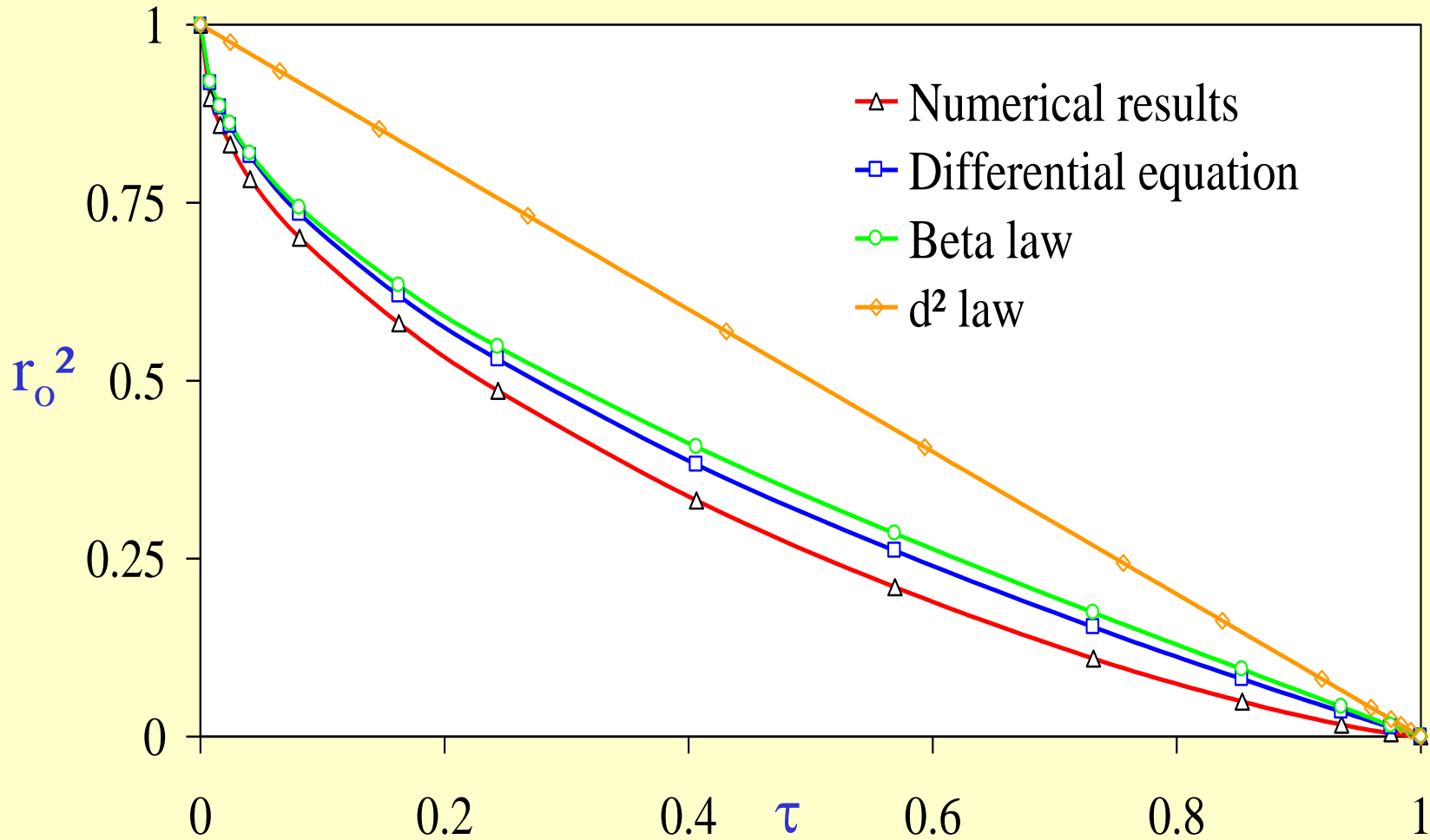
⇒ Calculation of the lifetime of the droplet of radius $r_o(\tau)$

⇒ The d^2 law is satisfied for r_m : $r_m^2 = 1 - \tau$

⇒ Approximate relation for r_o :

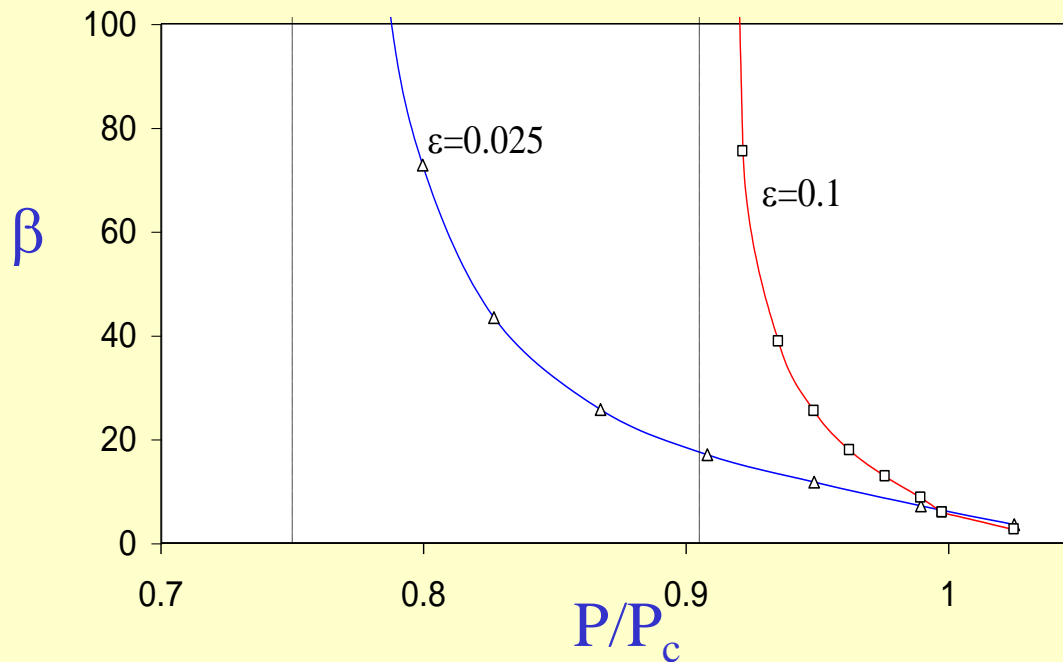
$$\left\{ \begin{array}{l} \dot{r}_o (r_m - r_o) = - \frac{\varepsilon}{\gamma_\infty} [m(\theta_c) - m(\theta_m)] \\ r_m^2 = 1 - \tau \\ r_o(0) = 1 \end{array} \right. \Rightarrow \boxed{r_o^\beta - \beta r_o = (1 - \beta) \sqrt{1 - \tau}}$$

with $\beta = \frac{\gamma_\infty}{2\varepsilon(m(\theta_c) - m(\theta_m))}$



Supercritical to clearly subcritical vaporization

★
$$r_o^\beta - \beta r_o = (1 - \beta) \sqrt{1 - \tau} \quad (1) \quad \text{with } r_o = r'_o / r'_{\text{initial}} \leq 1$$



⇒ (1) : $r_o \approx \sqrt{1 - \tau}$ for small P ($\beta \rightarrow \infty$) : the d^2 law is recovered

III) Conclusions, prospects

Conclusions

- ★ Determination of the law of regression for the droplet radius. Applied to limiting cases (subcritical situations, $\beta \gg 1$), this law becomes the “ d^2 law”. For slightly sub or supercritical pressures, $\beta = O(1)$.

Prospects

- ★ Application to evaporation in mixtures at high pressure (ex : liquid O₂ in H₂).
- ★ Determination of an effective surface tension in supercritical conditions.