COLLAPSE OF A CAVITATION BUBBLE IN HEAVY–MOLECULE LIQUIDS

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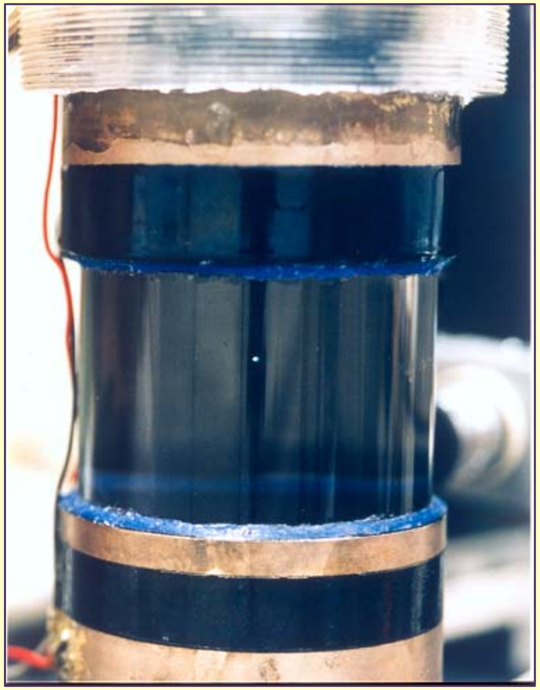
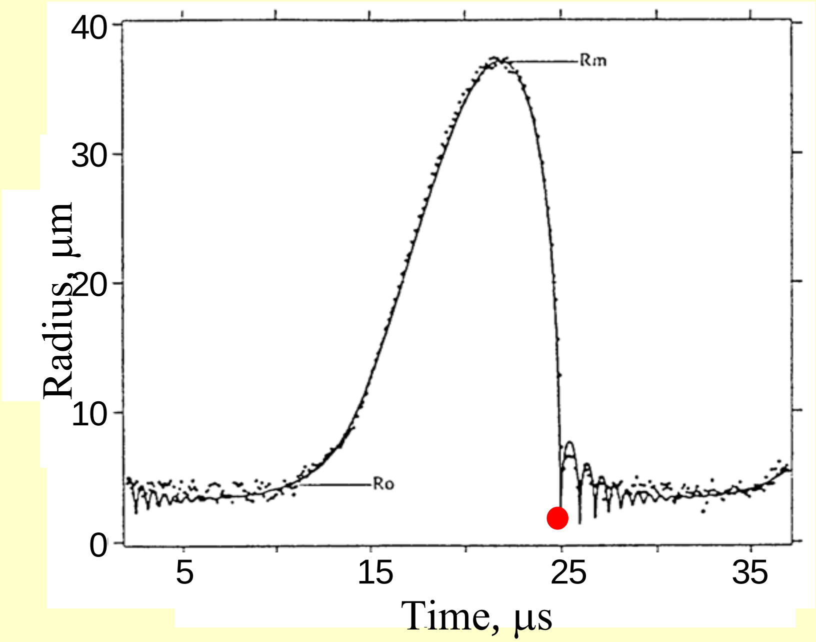
Introduction

Single Bubble Sonoluminescence, SBSL, 1990



Crum, Roy (Science, 266, 1994)



[B.P.Barber et al./Phys.Rep. 281(1997)]

Air bubble in water under room conditions

$p_L = p_0 + p_a \sin \omega t$

$R_0 \sim 5$ μm

$\omega \sim 26.5$ kHz

$p_a \sim 1.4$ bar

$R_{max} \sim 50$ μm

$R_{max} / R_0 \sim 10$

$R_{max} / R_{min} \sim 10^2$

Neutron emission in bubble cluster

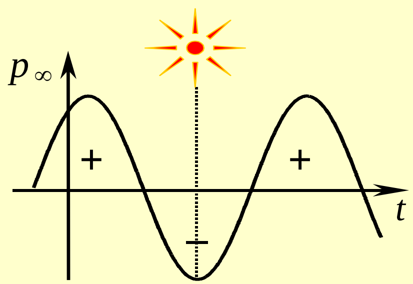
(R. Taleyarkhan, R. I. Nigmatulin et al, 2002-2005)

Liquid

1. Deuterated acetone (C_3D_6O)
2. Mixture of Deuterated acetone or benzol (C_6D_6) with organic liquid C_2Cl_4
3. Heavy water (D_2O)

Cavitation inception

1. Pulse neutron source

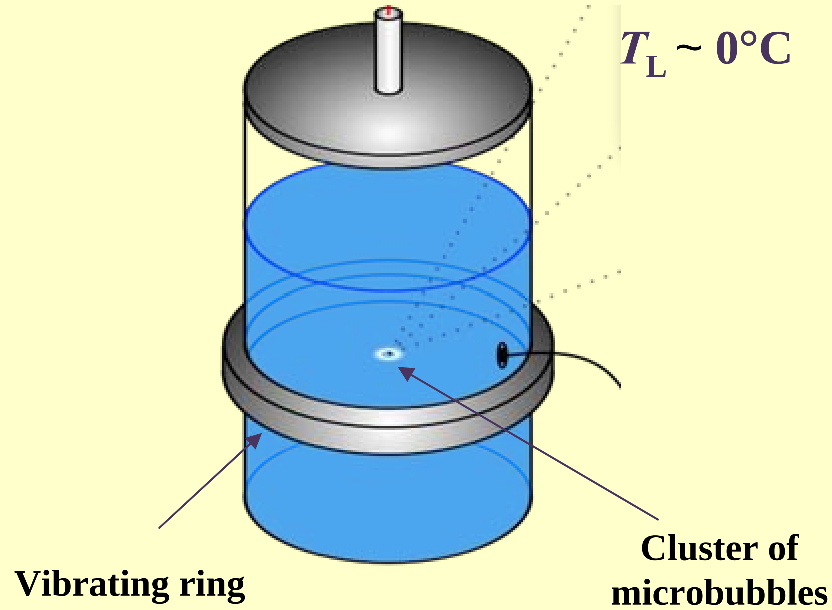


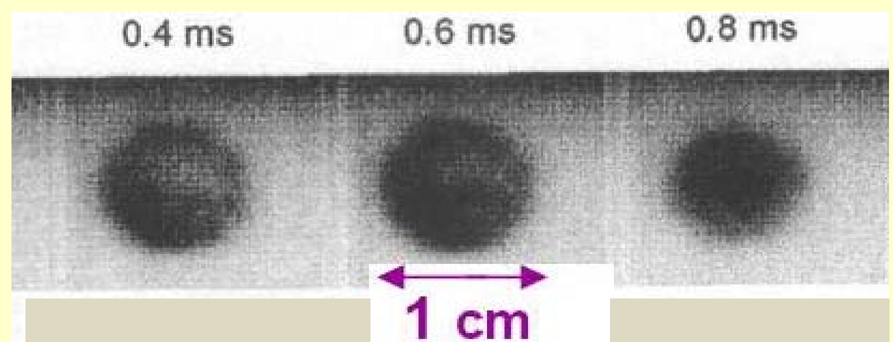
2. Continious neutron source
3. Admixture radiating alpha-particles with energy of ~4 MeV (uranium salt)

Liquid pressure

$$p_L = p_0 + p_a \sin \omega t$$

$p_0 \sim 1$ bar, $p_a \sim 15$ bar, $\omega \sim 2\pi$ 20 kHz,



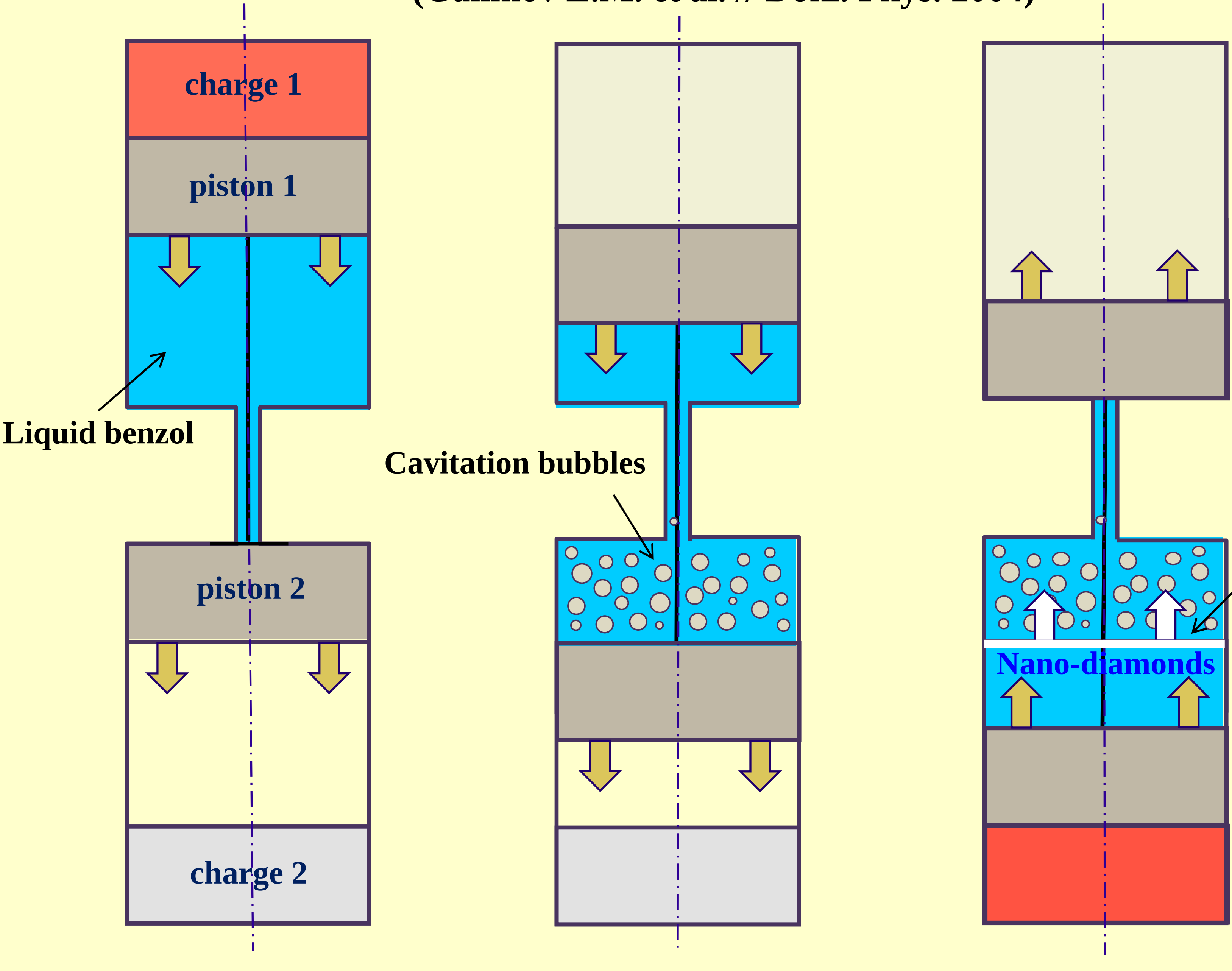


(Y.Xu, A.Butt // Nuc. Eng. & Design 2005)

$R_{max} \sim 500$ μm

Nano-diamond production in benzol

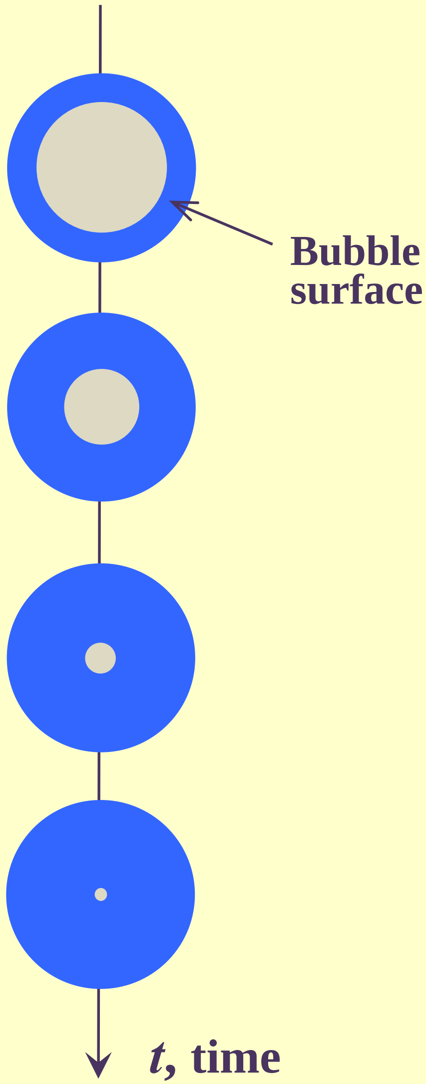
(Galimov E.M. et al. // Dokl. Phys. 2004)



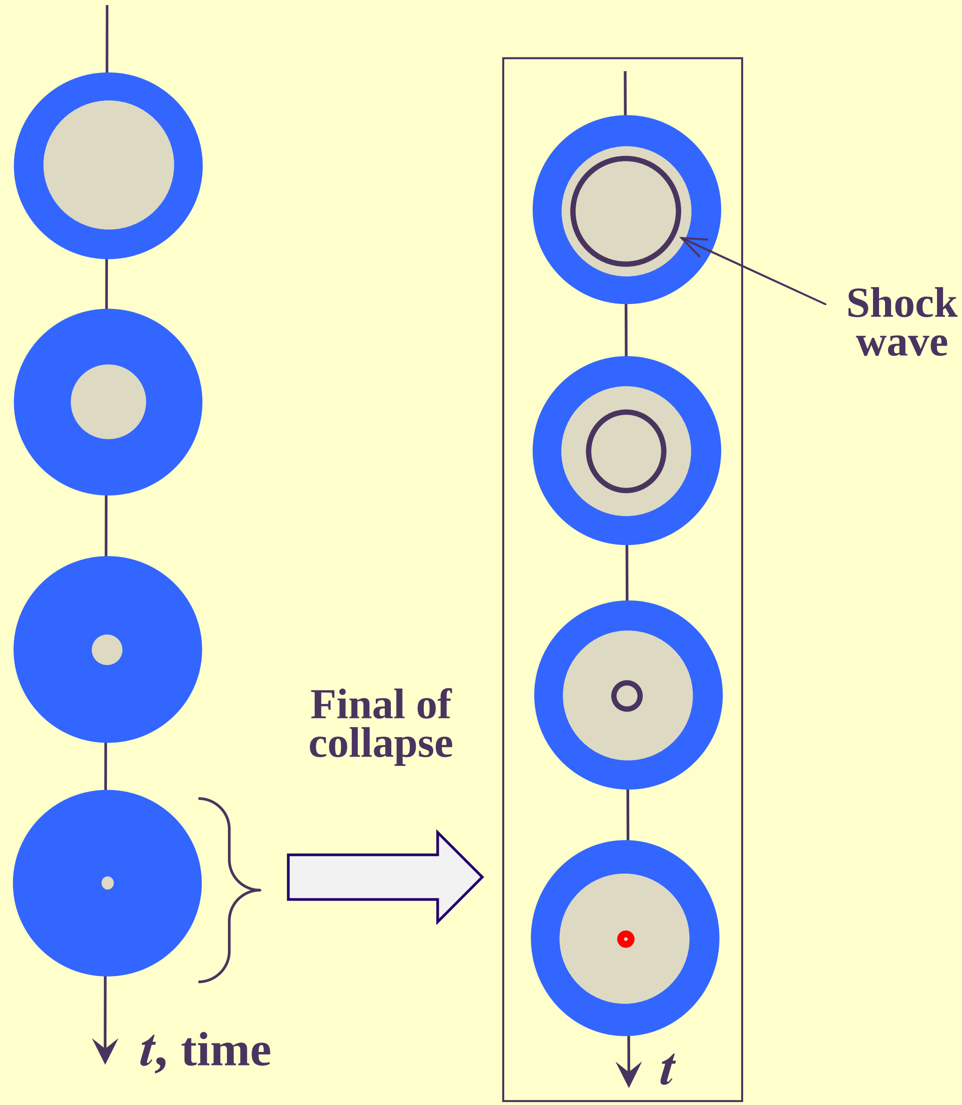
p_{sh} = 100 - 400 bar

Spherical bubble collapse scenarios

1. Shockless collapse



2. Collapse with a shock wave



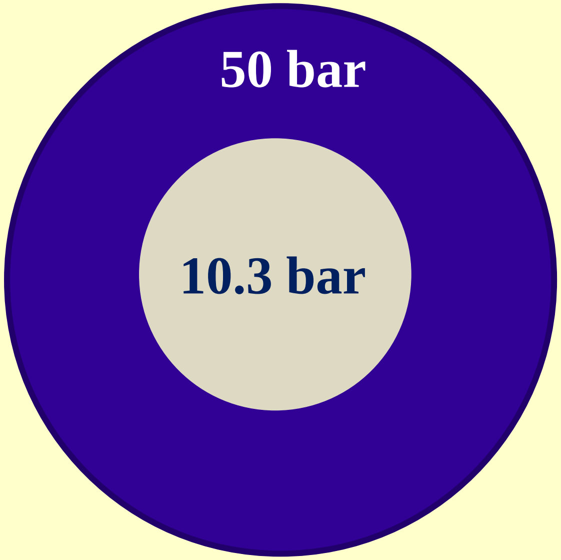
For realizing bubble collapse with shock waves inside a bubble, the gases with larger molar mass *M* and smaller specific heats ratio γ are preferable

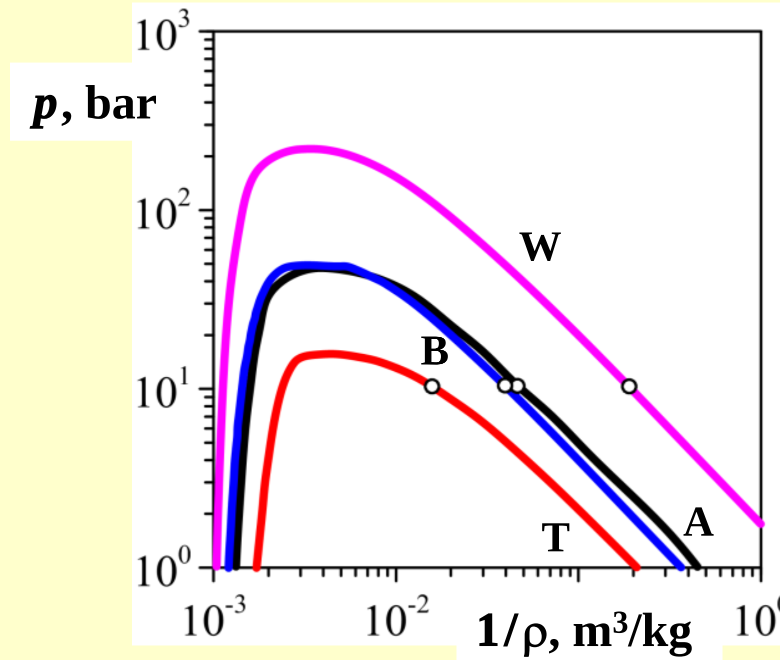
I. Problem statement

The goal of the present work is to compare such liquids as WATER, ACETONE, BENZOL, AND TETRADECANE

Liquid		M, g/mol	γ
Water	H_2O	18	1.325
Acetone	C_3H_6O	58	1.125
Benzol	C_6H_6	78	1.1
Tetradecane	$C_{14}H_{30}$	198	1.0265

II. Compression of vapor inside bubbles





	p_L, bar	p_S, bar	T_L, K	ρ_S, kg/m^3	ρ_l, кг/м^3
W	50	10.3	454	5.26	858
A	50	10.3	419	22.6	637
B	50	10.3	453	24.8	719
T	50	10.3	663	63.9	458

Mathematical model

Equations of fluid dynamics

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0,$$

$$\frac{\partial}{\partial t}(\rho \mathbf{u}) + \nabla \circ (\rho \mathbf{u}\mathbf{u}) + \nabla p = 0,$$

$$\frac{\partial}{\partial t}(\rho E) + \nabla \cdot \left[\left(p + \rho E \right) \mathbf{u} \right] = \nabla \cdot \left(\kappa \nabla T \right), \qquad E = \varepsilon + \mathbf{u}^2 / 2$$

Wide-range equations of state

$$p = p(\rho, T), \quad \varepsilon = \varepsilon(\rho, T)$$

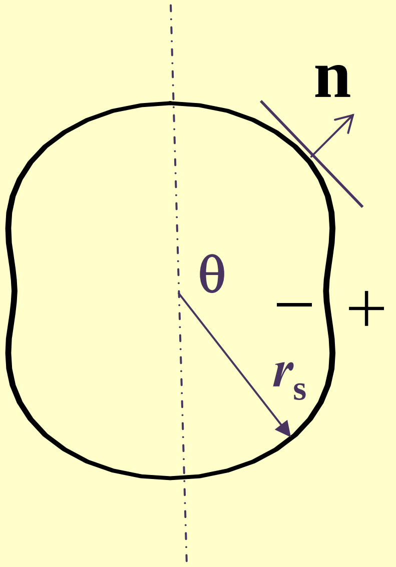
Boundary conditions

On the bubble surface $r = r_s(\theta)$

$$\rho^+\left(\mathbf{D}-\mathbf{u}^+\right)\cdot\mathbf{n} = \rho^-\left(\mathbf{D}-\mathbf{u}^-\right)\cdot\mathbf{n} = j,$$

$$\mathbf{n}\cdot\left\{\left[\left(p^+ - p^-\right)g - 2\mu e^+\right]\cdot\mathbf{n}\right\} = -\sigma\nabla\cdot\mathbf{n},$$

$$T^+ = T^-, \quad \left(\kappa\nabla T\cdot\mathbf{n}\right)^+ - \left(\kappa\nabla T\cdot\mathbf{n}\right)^- = j\,l$$

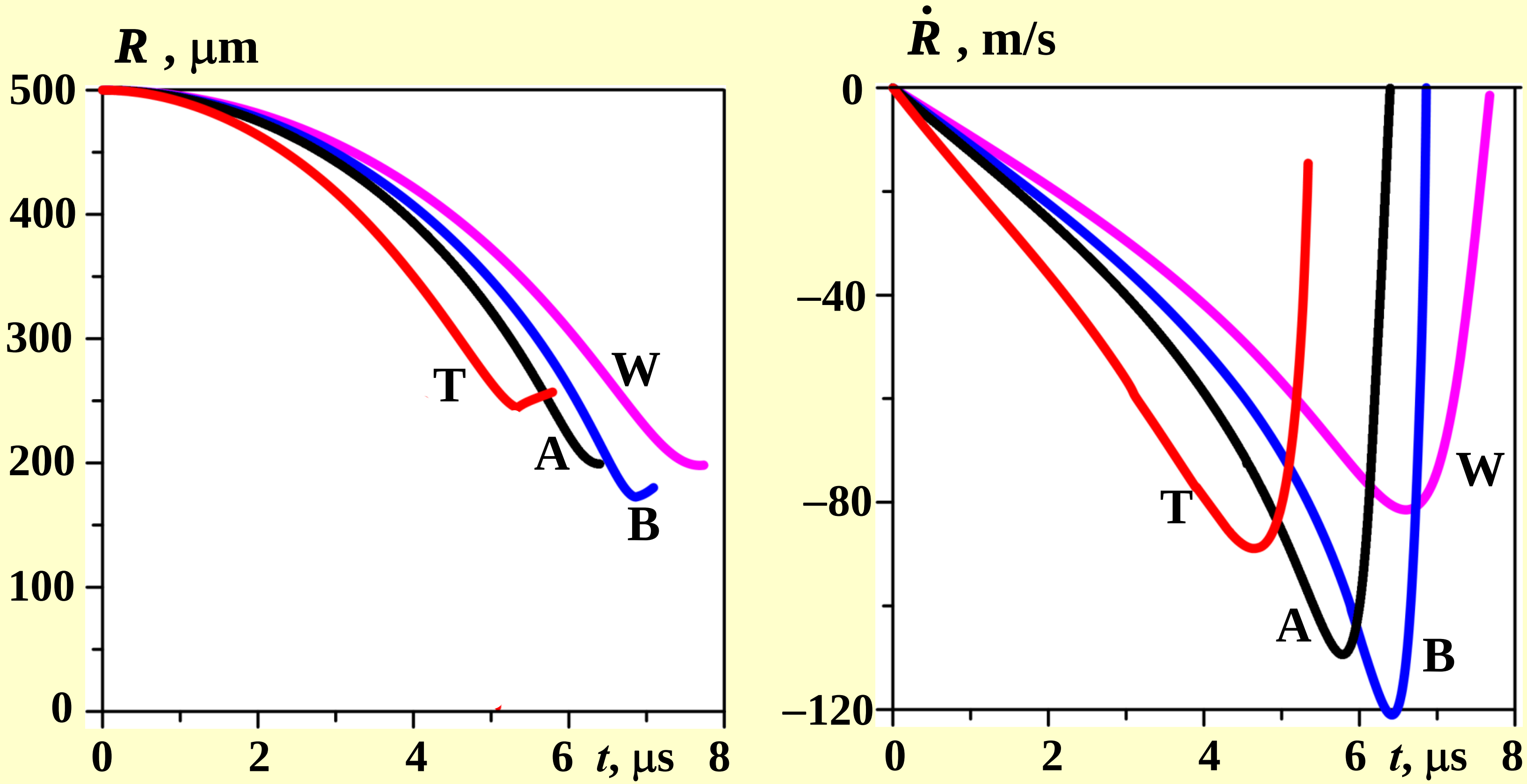


Far from the bubble

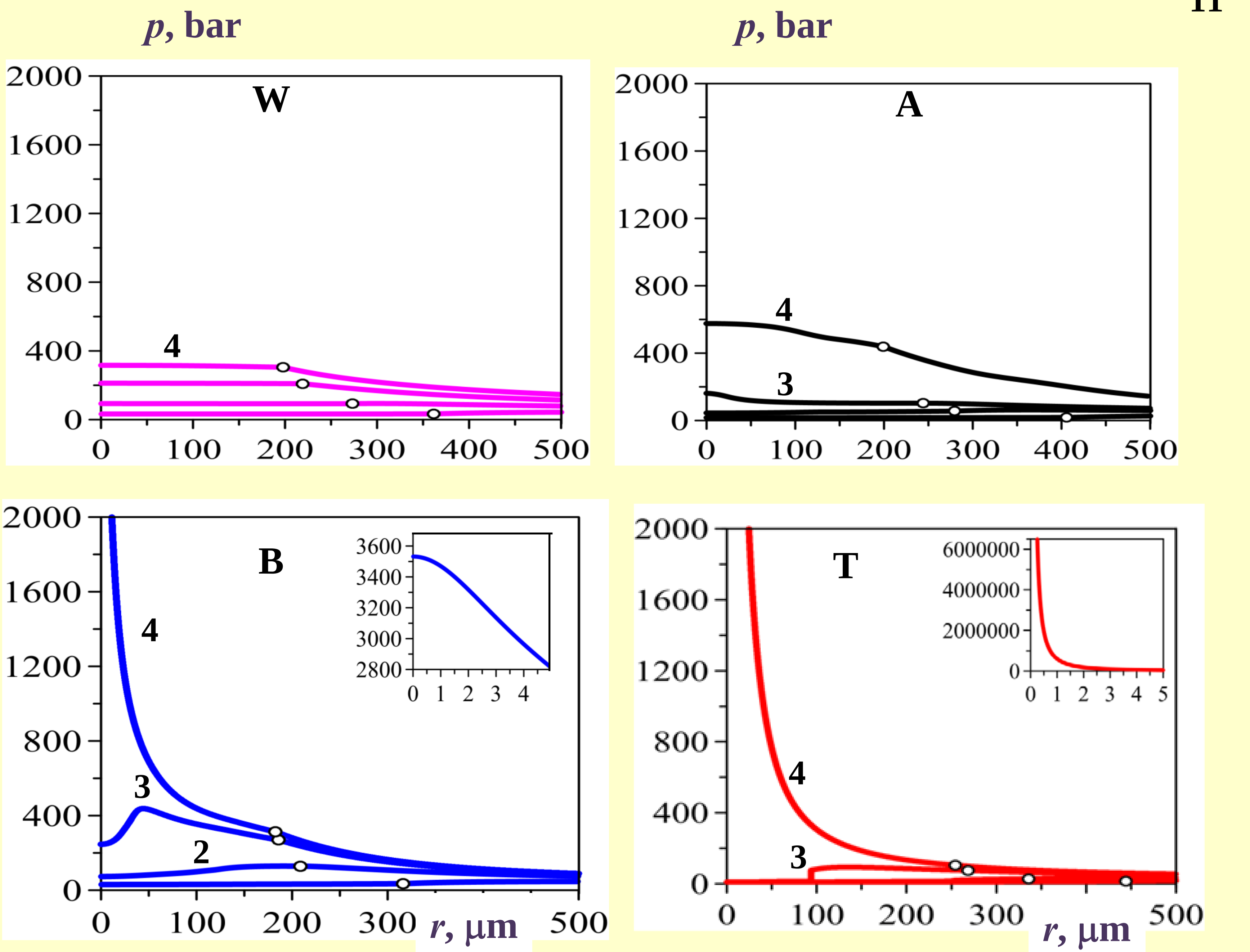
$$p = p_L, \qquad T = T_L$$

Computational results

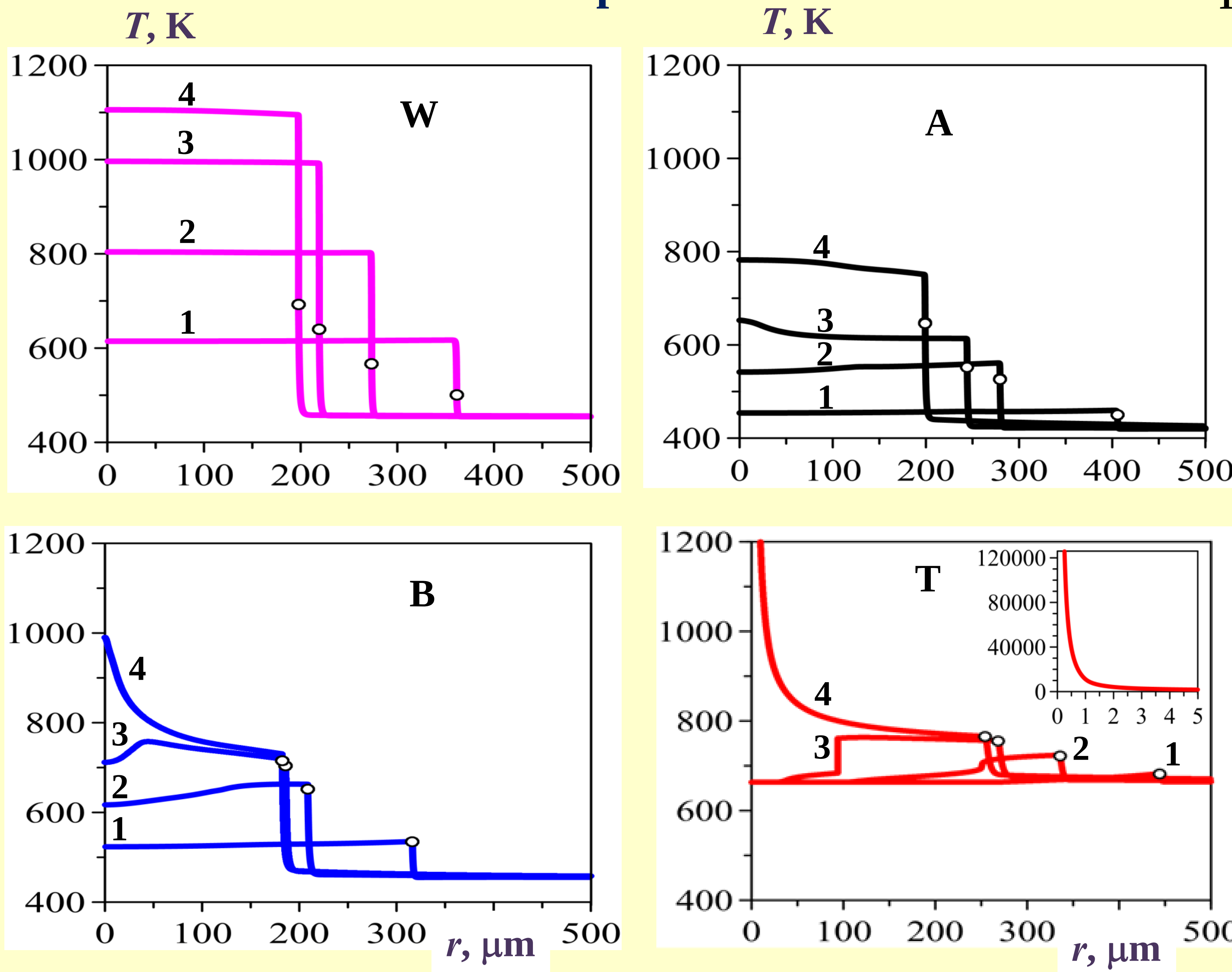
Bubble radius variation at collapse



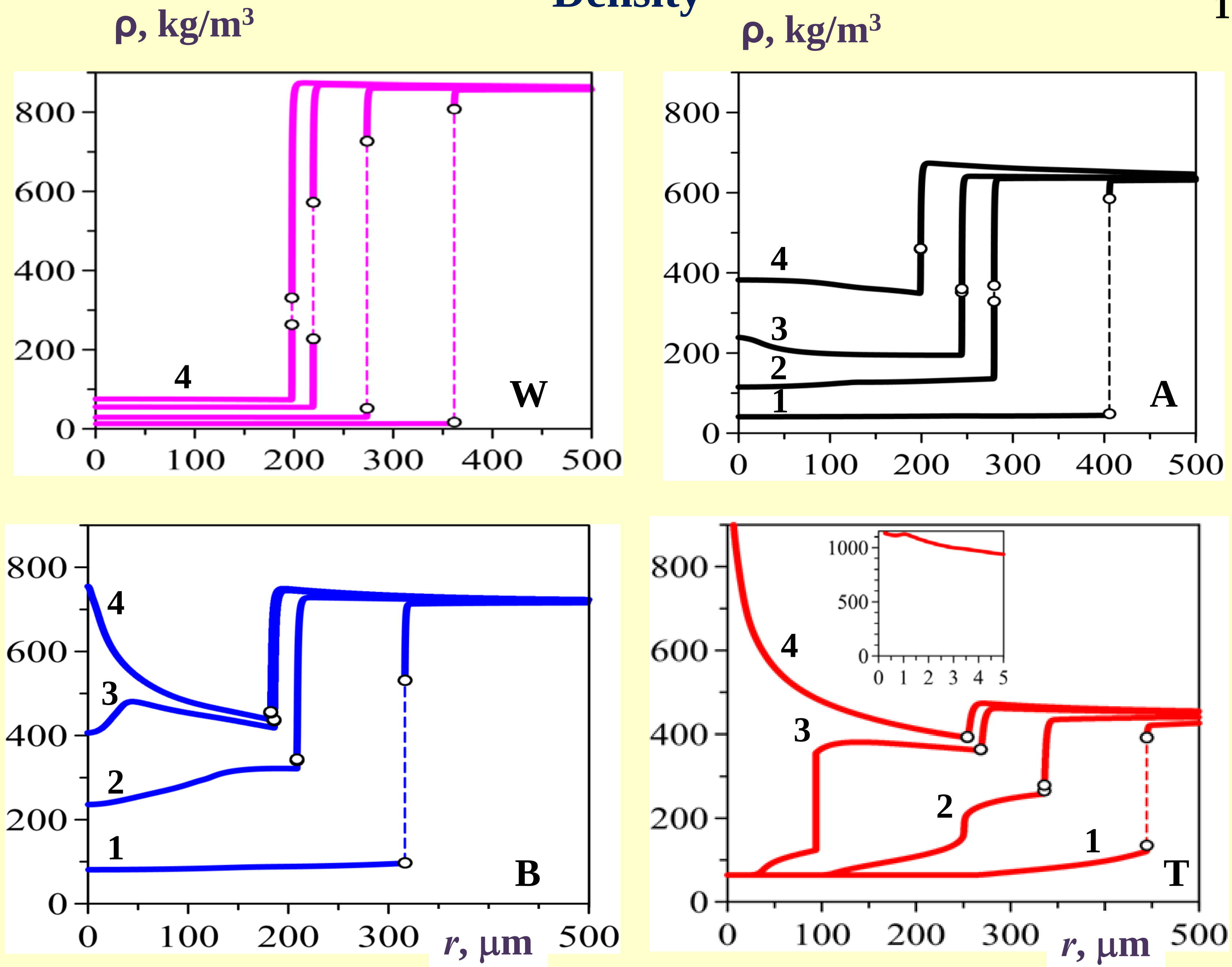
Pressure


p, bar
p, bar
W
4
2000
1600
1200
800
400
0
0
100
200
300
400
500
A
4
3
B
4
3
2
3600
3400
3200
3000
2800
0 1 2 3 4
r, μm
T
4
3
6000000
4000000
2000000
0
0 1 2 3 4 5
r, μm

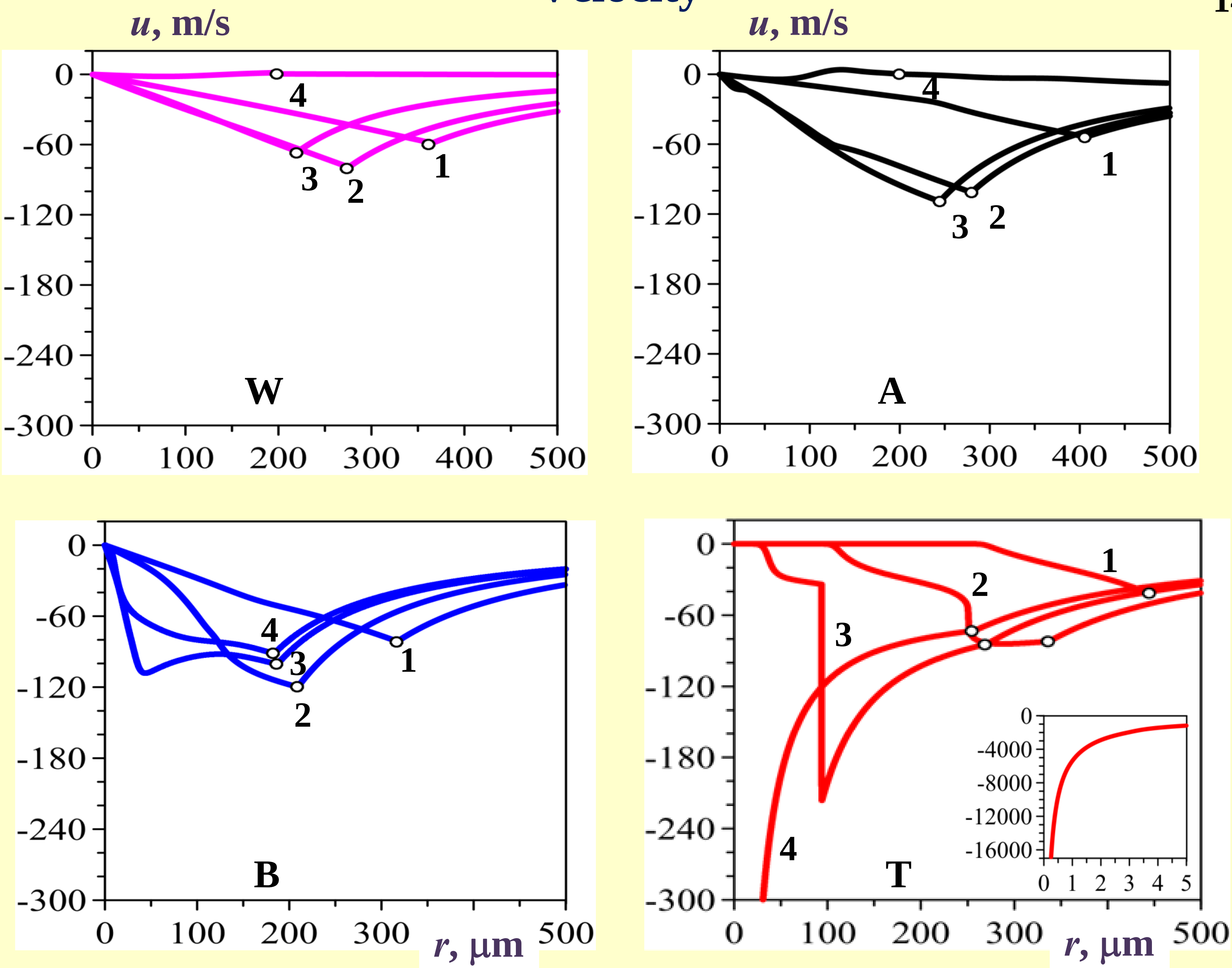
Temperature



Density


ρ, kg/m³
ρ, kg/m³
800
600
400
200
0
0 100 200 300 400 500
4
W
4
3
2
1
A
4
3
2
1
B
r, μm
4
3
2
1
T
1000
500
0
0 1 2 3 4 5
r, μm

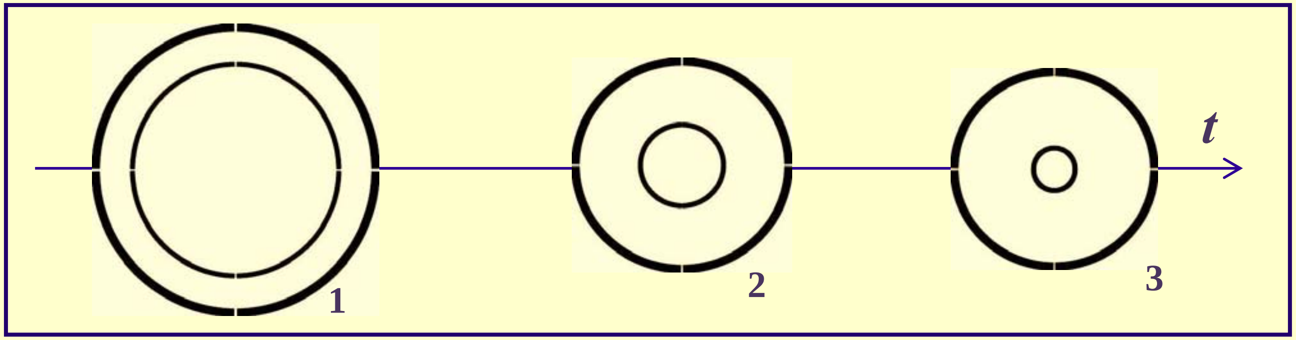
Velocity


u, m/s
u, m/s
W
A
B
T
r, μm
r, μm
1
2
3
4
0
-60
-120
-180
-240
-300
100
200
300
400
500
-4000
-8000
-12000
-16000

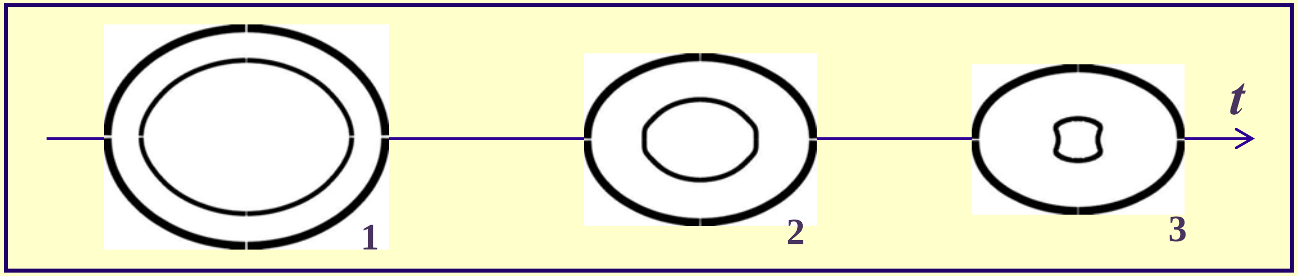
II. Bubble non-sphericity growth at collapse

Non-spherical bubble collapse scenarios

1. Small deformations of the bubble and shock wave

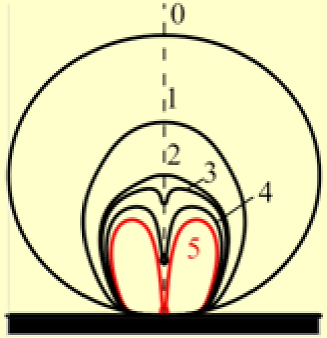


2. Small deformations of the bubble, large deformations of the shock wave



3. Bubble destruction

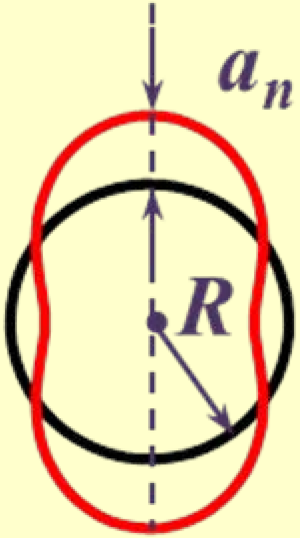
Bubble collapse near a wall:



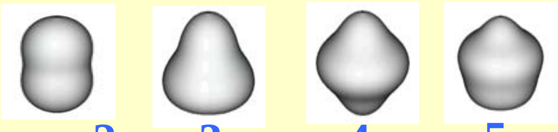
Mathematical model

Bubble surface equation

$$r = R(t)\left[1 + \varepsilon_n(t) P_n\left(\cos\theta\right)\right]$$



$\varepsilon_n = a_n / R$



$n = 2$ 3 4 5

Equation of the bubble sphericity disturbance

$$(1+q_n)\ddot{a}_n+\left[3\frac{\dot{R}}{R}+2(n+1)(n+2)\frac{\nu_L}{R^2}\right]\dot{a}_n+$$

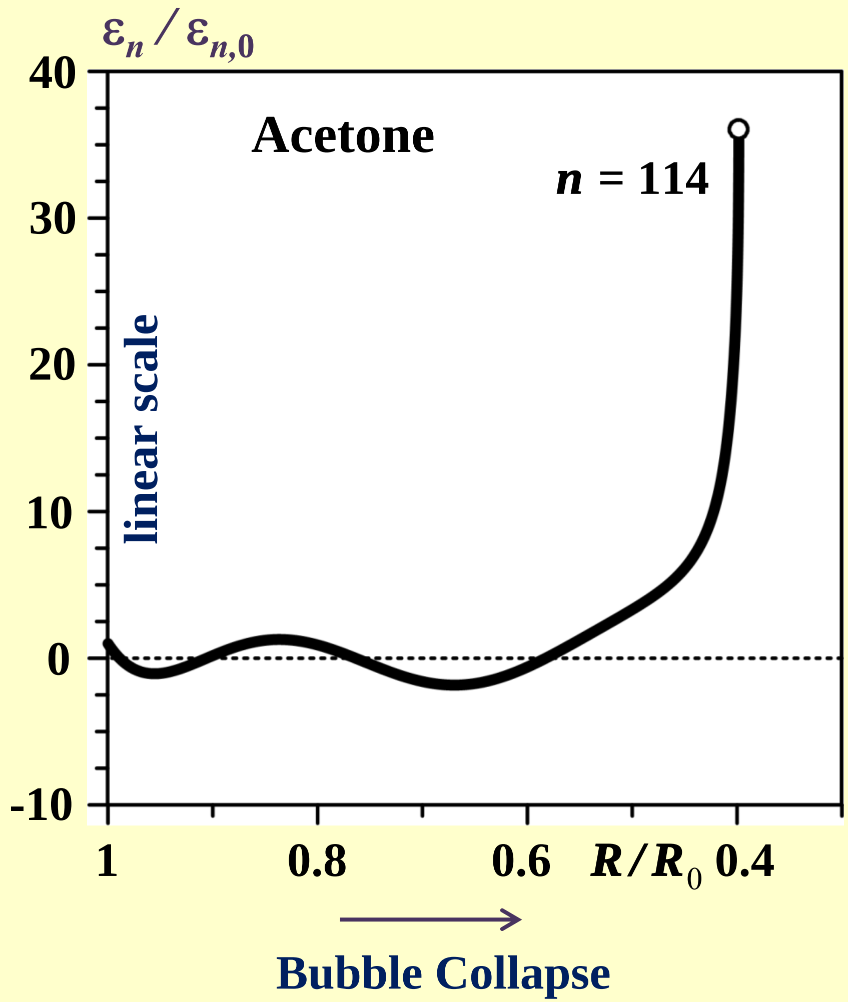
$$+\left[\omega_n^2+\frac{4\nu_L\left(n^2-1\right)\dot{R}}{R^3}-(n-1)(1-q_n)\frac{\ddot{R}}{R}\right]a_n=0$$

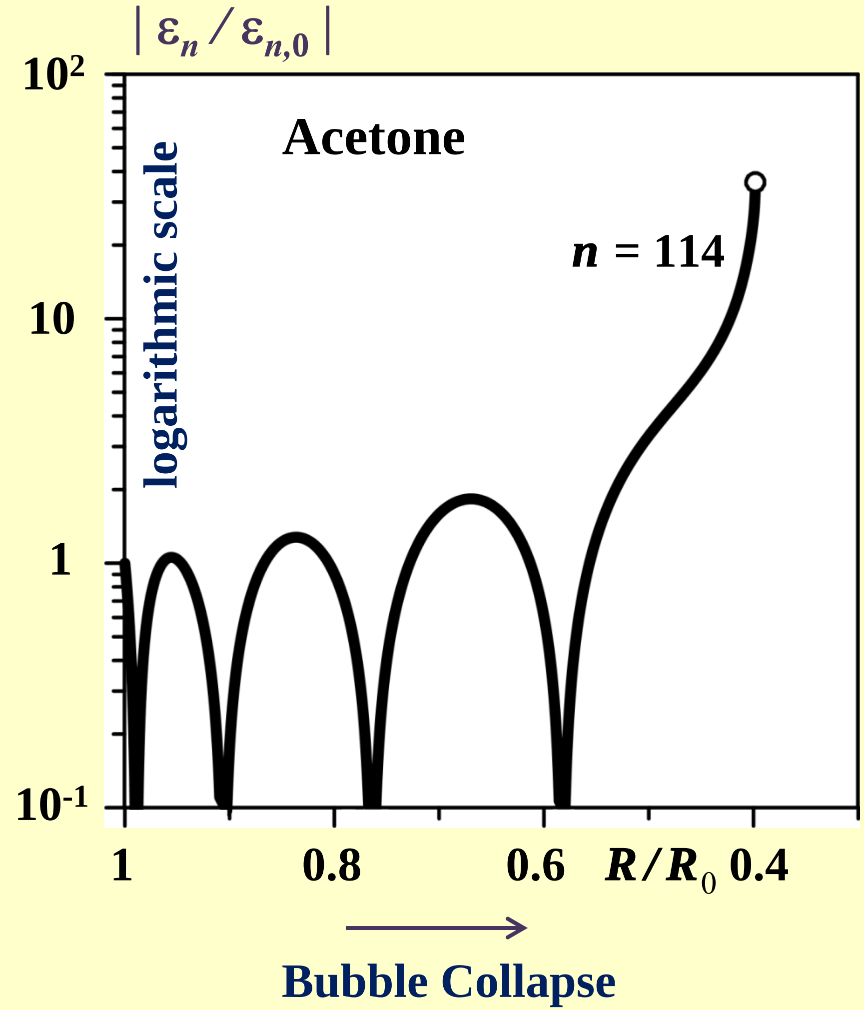
где

$$\omega_n^2=\frac{\sigma\left(n^2-1\right)(n+1)}{\rho_{L,\Gamma}R^3},\qquad q_n=\frac{(n+1)\overline{\rho}_G}{n\rho_{L,\Gamma}}$$

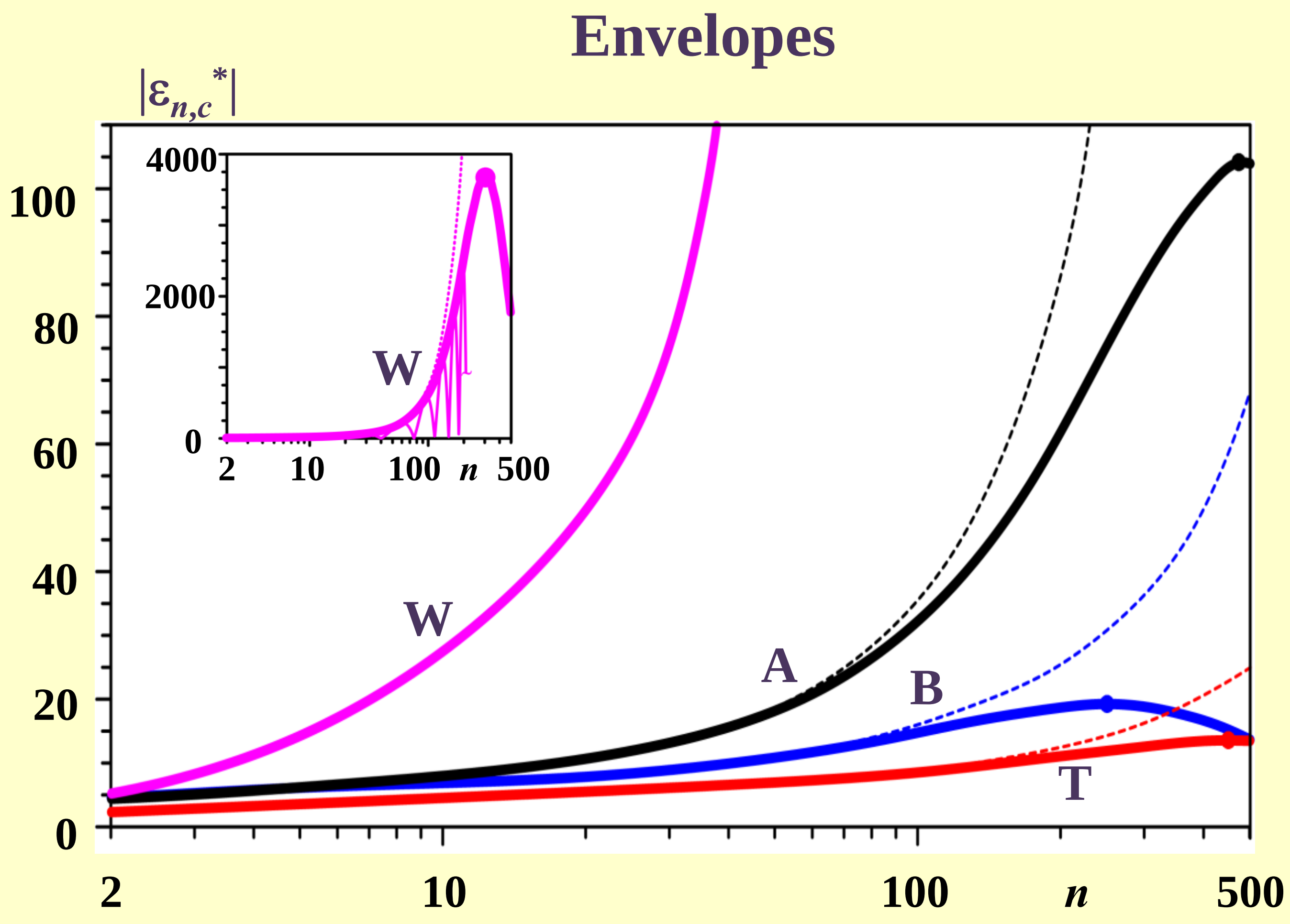
Computational results

Features of the non-sphericity growth





Bubble non-sphericity growth



Conclusions

1. Among water, acetone, benzol, and tetradecane, tetradecane is preferable for producing shock waves inside a cavitation bubble. Then benzol goes and after that acetone. Water is the worst variant.

2. Similar relationship also takes place with respect to preserving the bubble sphericity at collapse.

СПАСИБО ЗА ВНИМАНИЕ !