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ЗАБАБАХИНСКИЕ НАУЧНЫЕ ЧТЕНИЯ 2019

РОСАТОМ

ГОСУДАРСТВЕННАЯ КОРПОРАЦИЯ ПО АТОМНОЙ ЭНЕРГИИ «РОСАТОМ»

MODELINF OF RICHTMYER-MESHKOV, RAYLEIGH-TYLOR AND KELVIN-HELMHOLTZ INSTABILITY DEVELOPMENT ON POWER LASER FACILITIES

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RFNC–VNIITF

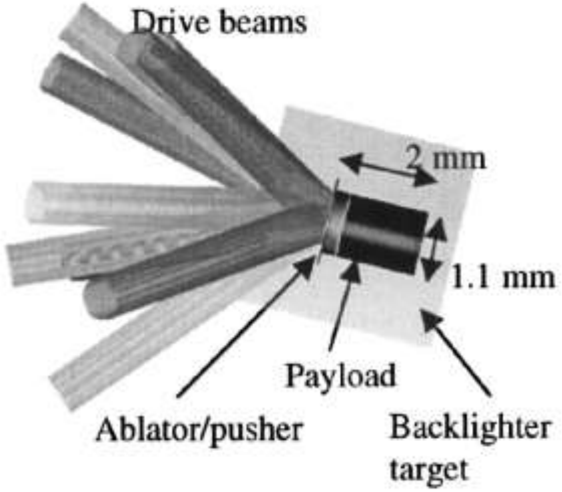
Power Laser Facilities

GARPUN	100 ns	100 J		$I = 2\text{-}5 \cdot 10^8 W/cm^2$
NIKE	4 ns	300 J	56 beams	$I = 1.4 \cdot 10^{12} W/cm^2$
ISKRA-4	1.2 нс		4 beams	$I = 0.5\text{-}1 \cdot 10^{14} W/cm^2$
SG-II	2 ps	1.5 kJ	8 beams	
SG-IIUp	3 ns	40 kJ	8 beams	
SG-III	3 ns	200 kJ (2012)	48 beams	1.4 MJ (2020)
OMEGA	1 mc	5 kJ	10 beams	$I = 6 \cdot 10^{14} W/cm^2$
NIF		1.8 MJ	192 beams	
Laser	**3 ns**	**2 kJ**		

Power Laser Facilities allow investigating fluids subjected to strong compression at high density energies.

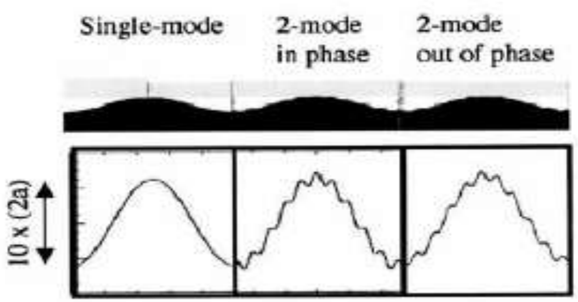
OMEGA: RT-RM instabilities miniature shock tube

A.R. Miles, M.J. Edwards, B. Blue, J.F. Hansen, H.F. Robey, R.P. Drake, C. Kuranz, and D.R. Leibrandt The effect of a short-wavelength mode on the evolution of a long-wavelength perturbation driven by a strong blast wave/ Physics of Plasmas 11, 5507 2004.

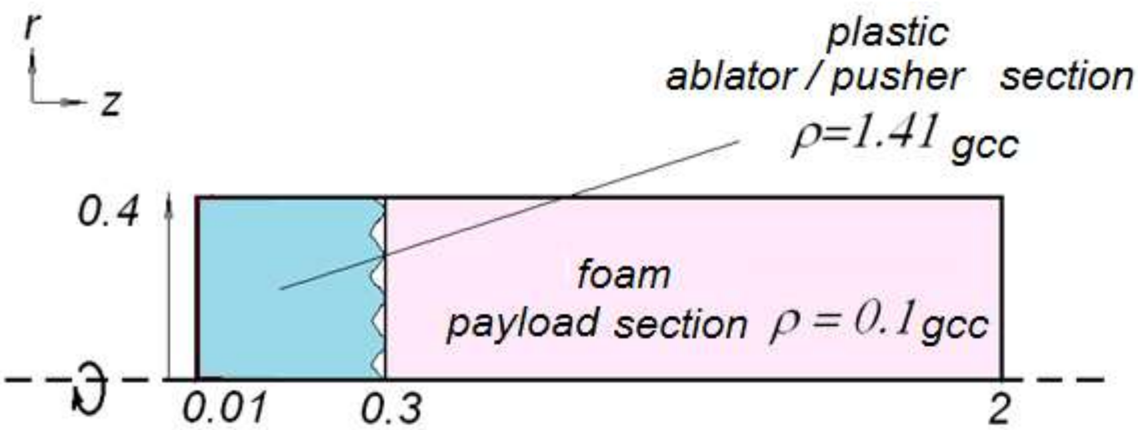


E = 5 kJ,
τ = 1 ns,
10 beams

r_f = 515 mkm
100 ps



Mode 1: $\lambda = 50$ µm, a = 2.5 µm (ka = 0.3), 120 ppw
Mode 10: $\lambda = 5$ µm, a = 0.25 µm (ka = 0.3), 12 ppw



Simulation code FOCUS*

*N.A. Mikhailov, I.V. Glasyrin, Method of contact bound steepening for the simulation of 3D multiphase compressible flows in Euler variables Zababakhin Scientific Talks international Conference March 20-24, 2017 Abstracts– Snezhinsk: RFNC-VNIITF, c. 326, 2017.

Euler equations of multicomponent gas dynamics in Cartesian coordinate system

$$\frac{\partial \vec{u}}{\partial t} + \nabla \cdot \overline{\overline{f}}(\vec{u}) = \vec{b}$$

Vector of quasiconservative variables

$$\vec{u} = \left(\rho_1\alpha_1, \ldots, \rho_N\alpha_N, \rho v_x, \rho v_y, \rho v_z, \rho E, \alpha_1, \ldots, \alpha_{N-1}\right)'$$

$\overline{\overline{f}}$ consists of physical flow vectors $\left(\vec{f}_x, \vec{f}_y, \vec{f}_z\right)$

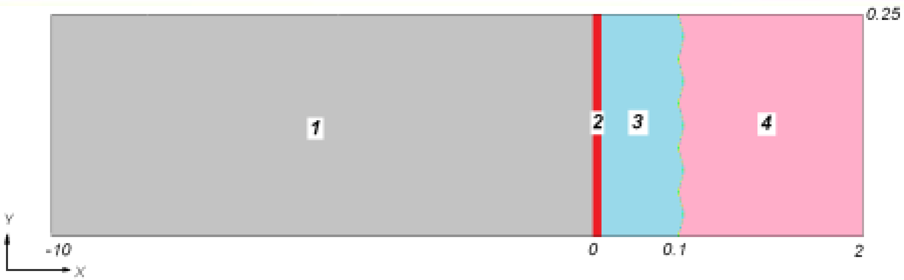
$\alpha_k = V_k/V$ - volume fraction of k-component

Simulation is carried out on 3D unstructured grid composed of arbitrary polyhedrons using finite volume method for discretization.

*Normal flows in cell face center are determined by **Godunov ty**pe scheme (HLL).*
*Flows in mixed cells are calculated accounting boundary between two fluids: geometric **VoF***
TVD piecewise linear multidimensional 3D reconstruction is used for value restoration.
***Hancock** method is used for time discretization*

Second order scheme on space and time!

Problem Statement 2D



- EOS ideal gas
- equal pressure $P_3 = P_4$
- interface SIN: **λ = 50 mkm**, A= **2.5 mkm**

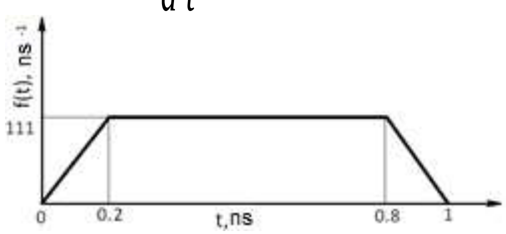
$$P = (\gamma\text{-}1)\,\rho\, C_v T.$$

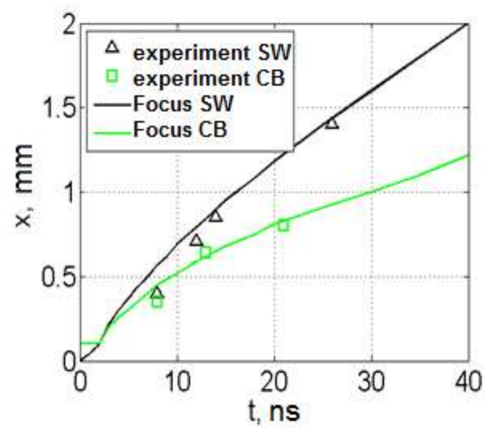
- Regions 2-4 have square grid Δ = 0.5 mkm:
  λ = 100 cells, amplitude = 5 cells.
- BC: left-right – free; top-bottom – walls

№	fluid	Density, ρ gcc	γ	C_v, 10^4kJ/(g$\times$keV)	Temperature T, keV	Wigth, mm
1-	He	0.01	5/3	3.6	1.0×10^{-3}	10
2	plastic	1.41	5/3	10	2.5×10^{-5}	0.01
3	plastic	1.41	5/3	10	2.5×10^{-5}	0.1
4	foam	0.1	7/5	10	4.5×10^{-5}	1.9

Energy release: **uniformly on** focal spot during 1 ns on skin depth h = 10 mkm.

$$\frac{dE}{dt} = E_0 \cdot f(t)$$





E_0 = 0.175 GJ/(g·ns)
absorption coefficient of laser energy 35%.

SW & CB coordinate

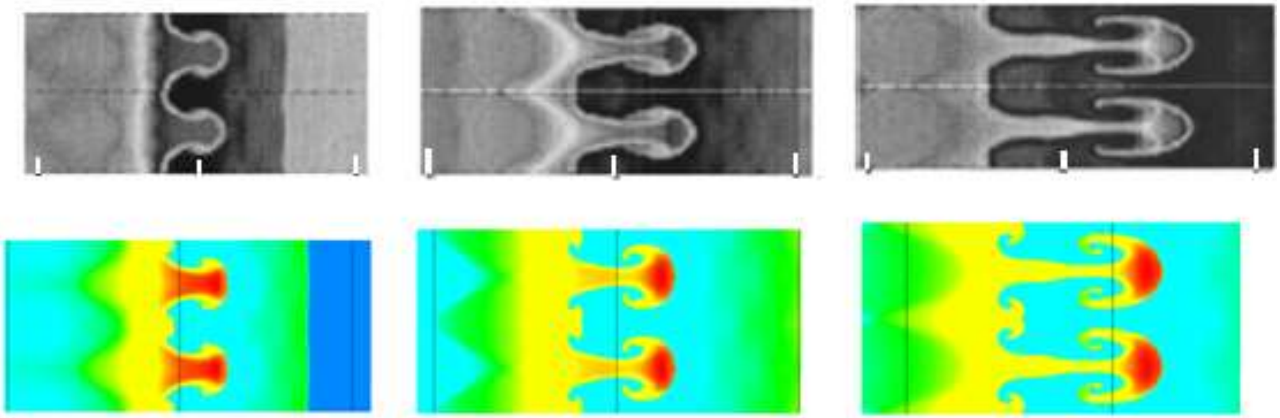
CALE *- FOCUS

* R. T. Barton, *Numerical Astrophysics* (Jones and Bartlett, Boston, 1985).

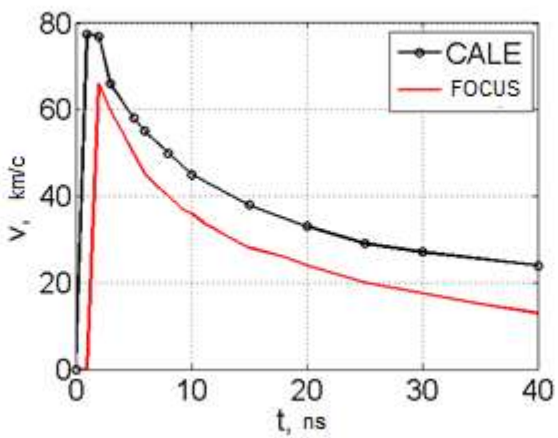
4 ns | 6 ns | 8 ns

CALE

FOCUS



1 mark = 100 mkm

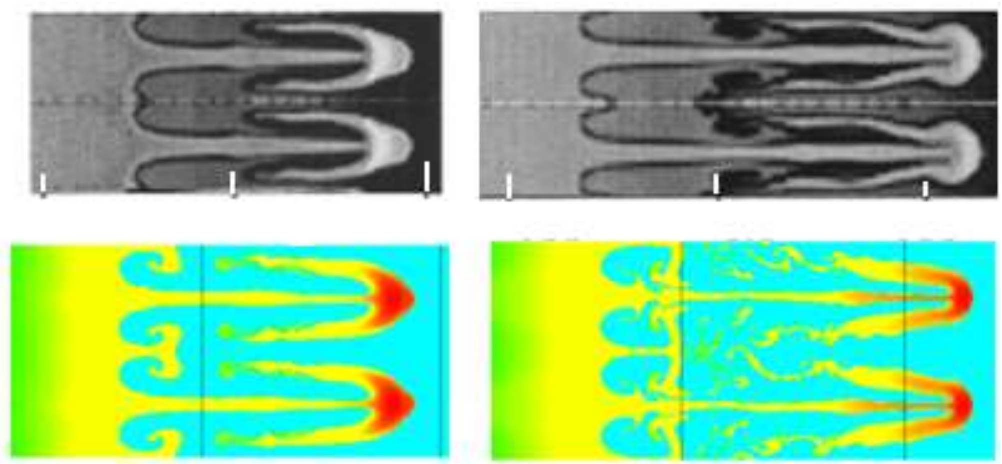


Interface velocity

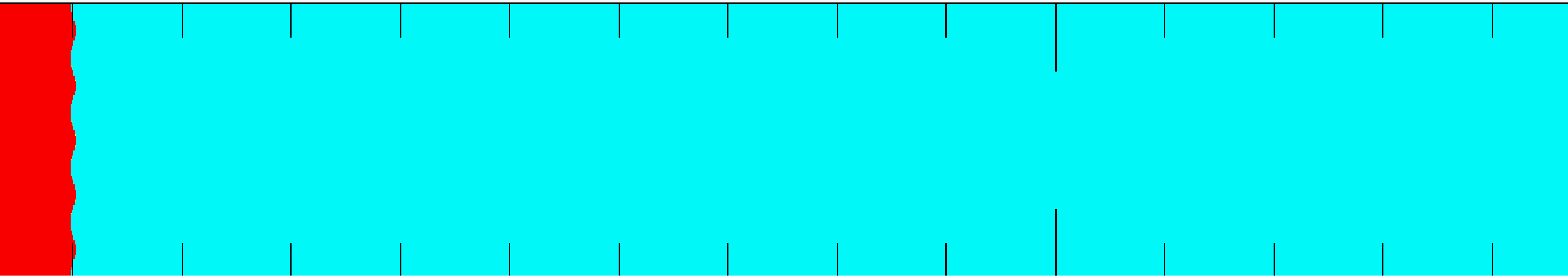
12 ns | 16 ns

CALE

FOCUS



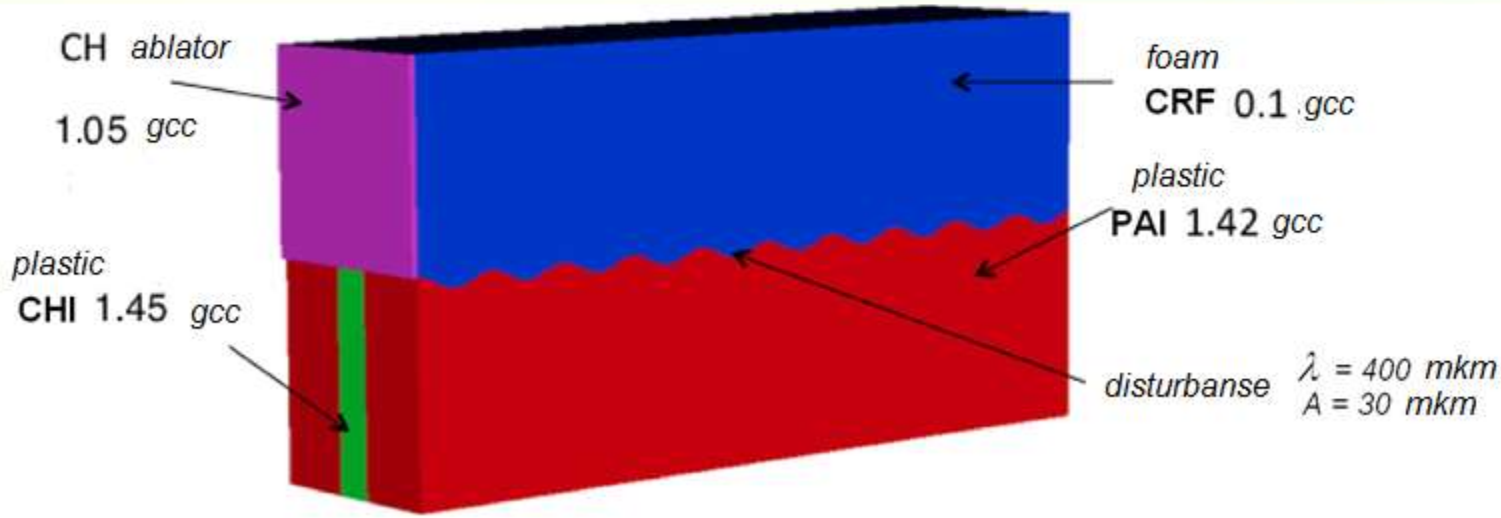
Bubbles and Spikes dynamics

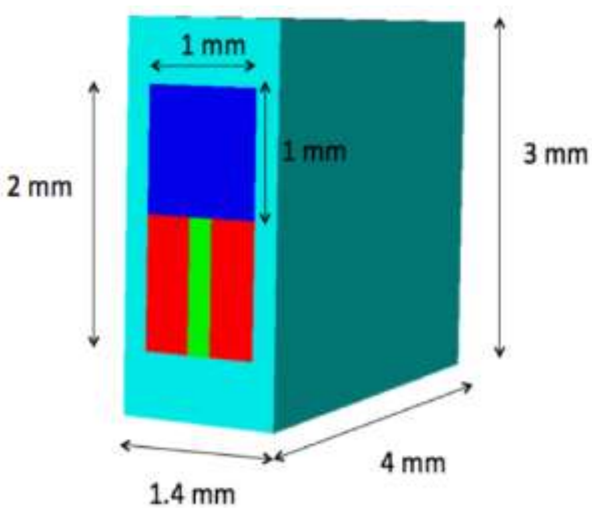


Density in constant range 0.004 - 0.4 gcc

OMEGA: KH instability

(*) K.S. Raman, O.A. Hurricane, H.S. Park, B.A. Remington, H. Robey, V.A. Smalyuk. Three-dimensional modeling and analysis of a high energy density Kelvin-Helmholtz Experiment Physics of Plasmas, 22 2012. LLNL-JRNL-531731.

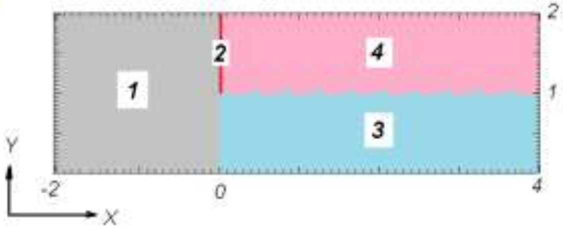




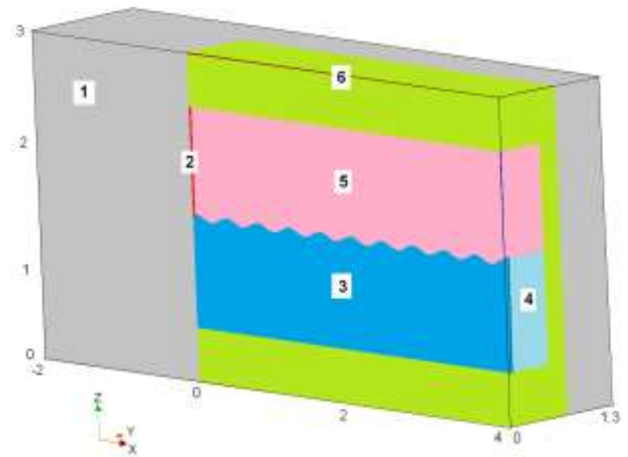
$E = 4$ kJ, $\lambda = 0.351$ mkm
$r_f = 430$ mkm
10 beams, $\tau = 100$ ps

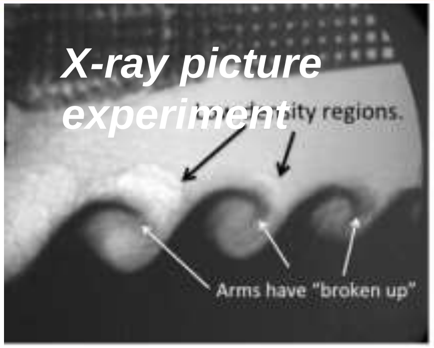
Problem Statement 2D, 3D

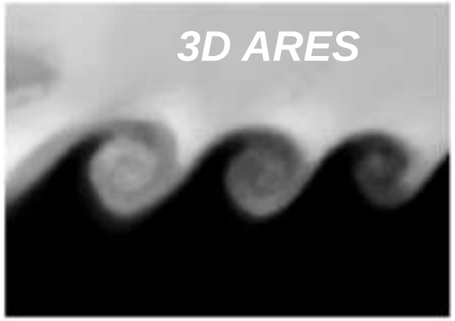
2D



3D

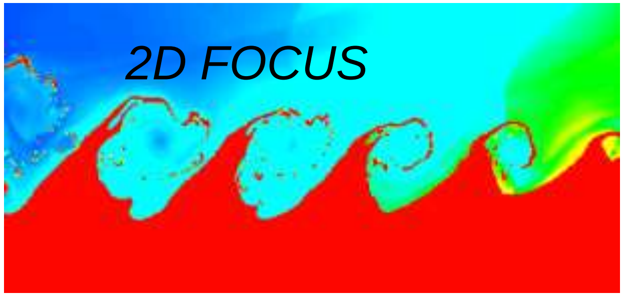






- EOS ideal gas
- equal pressure in 3-5 regions
- disturbance SIN

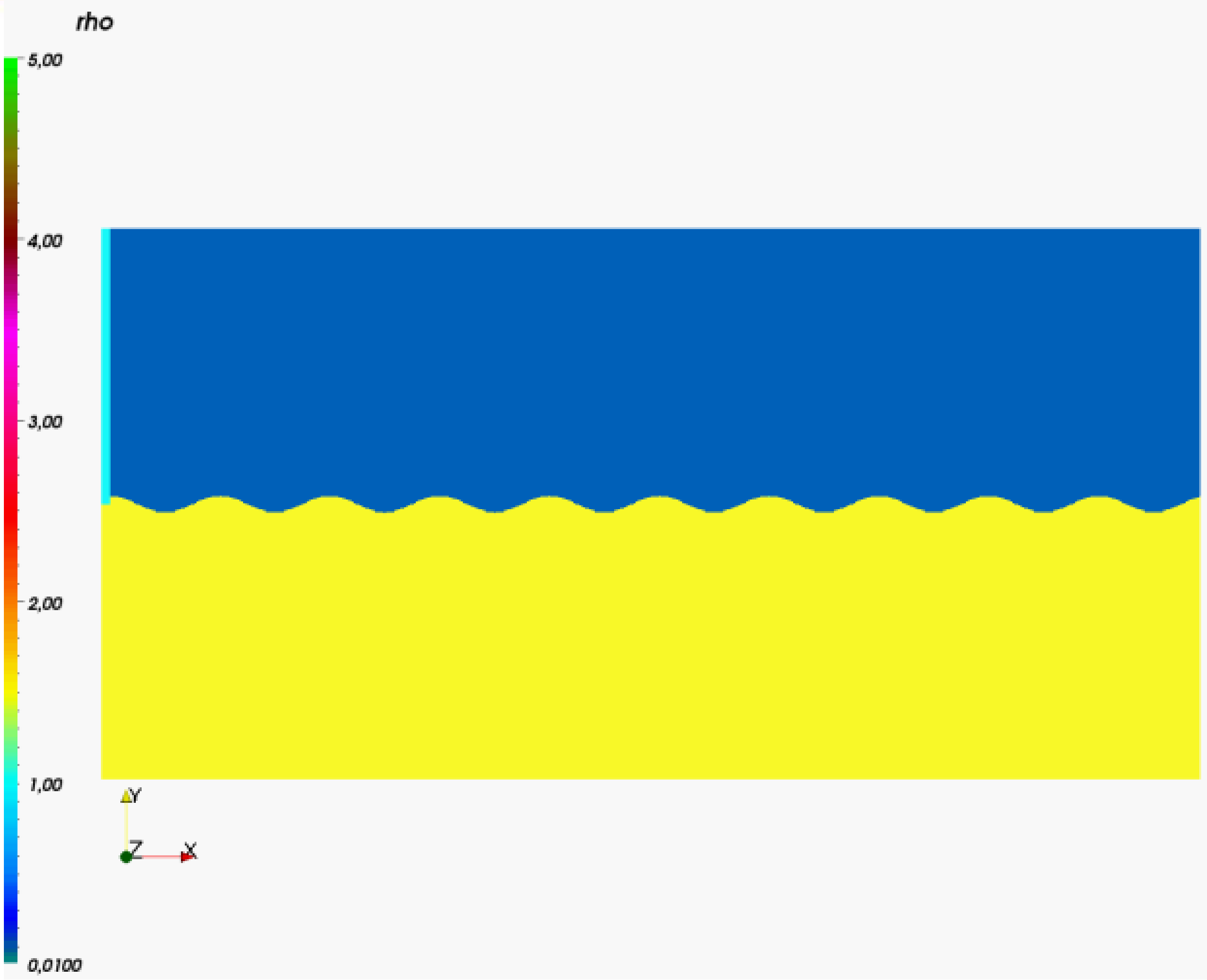
λ = 400mkm, A= 30 mkm



- regions 2-4 square grid Δ = 1 (15) mkm:, λ = 400 (26) cells, A – 30. (2) cells
- BC 2D: left-right – free; top-bottom – walls
- BC 3D: y = 0 – symmetry plane, other -- free

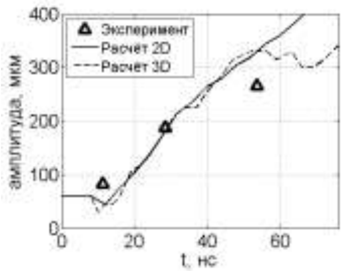
regions	1	2	3	4	5	6
density	He	plastic	plastic	plastic	foam	Be
ρ, gcc	0.01	1.05	1.45	1.41	0.1	1.84

Rollup height dynamics

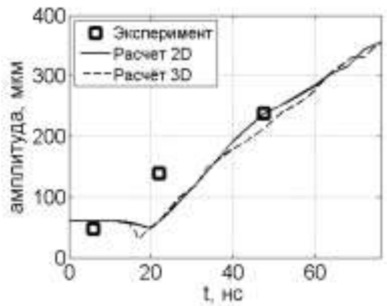


Peak-to-valley height

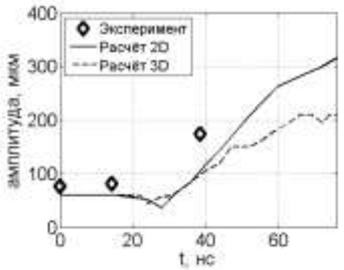
2[nd] rollup



3[rd] rollup



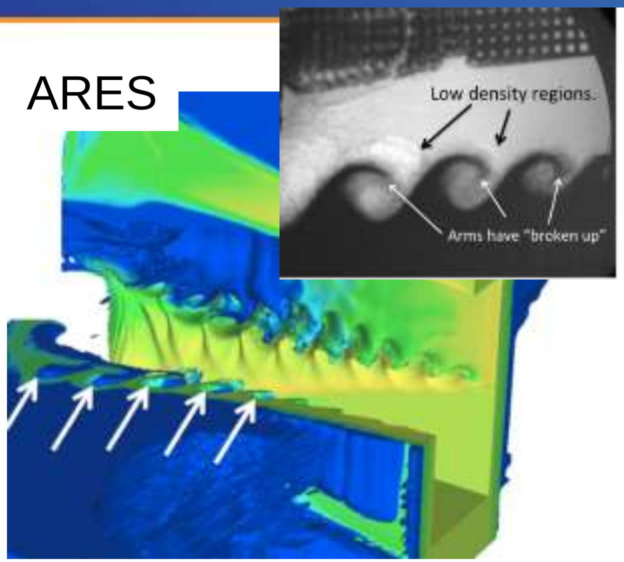
4[th] rollup

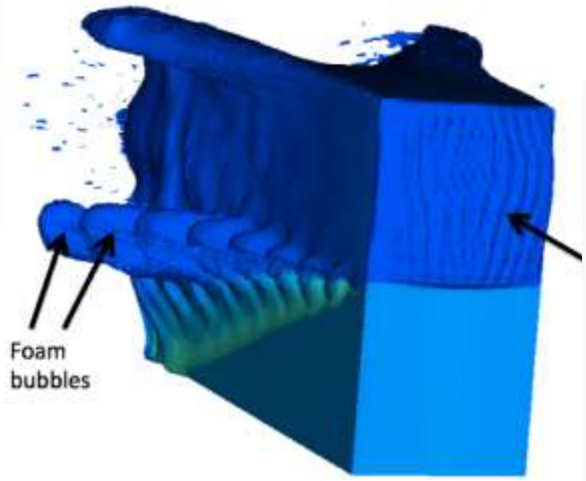


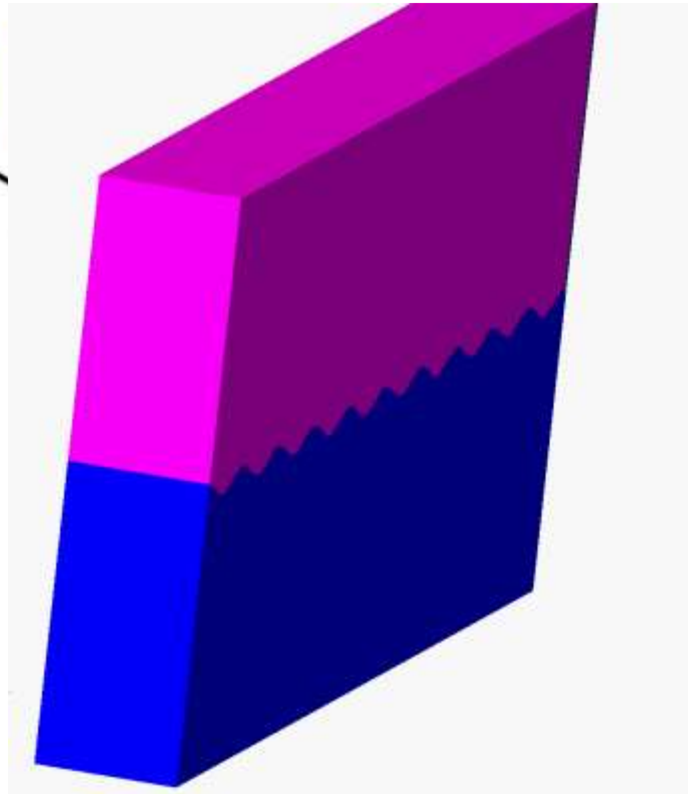
ARES* - FOCUS

R.M. Darlington, T. L.McAbee, and G. Rodrigue, Comp. Phys.Comm. 135, 58 (2001)

ARES

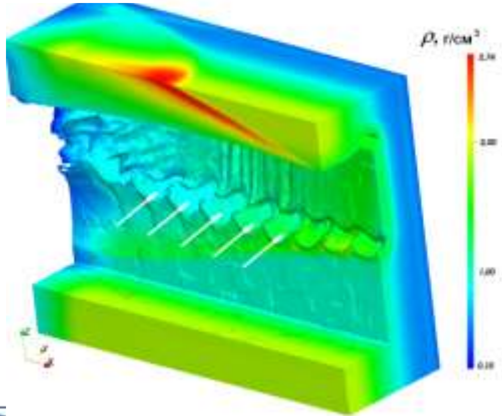


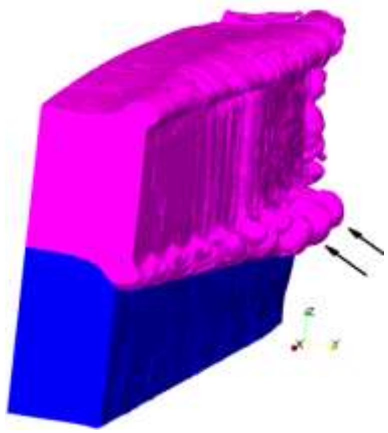




Distribution: foam (on the left) plastic (on the right)
at the moment of SW escaping domain

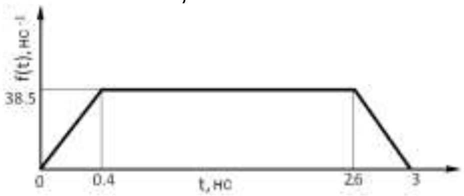
FOCUS





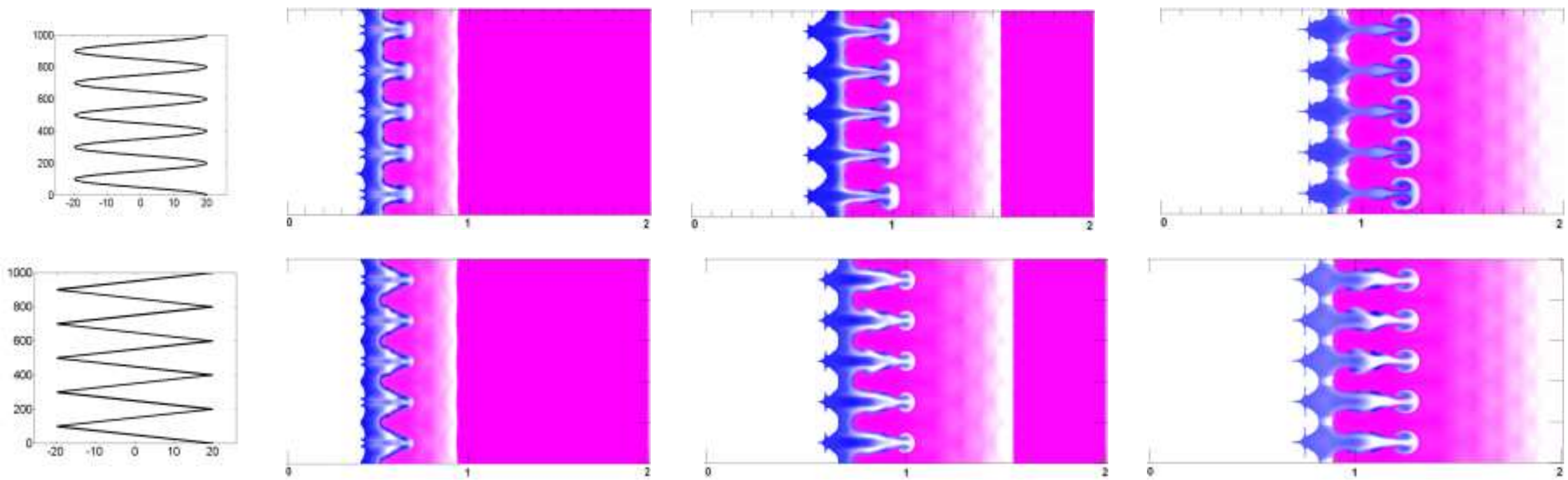
Prediction for E = 2 kJ
RT-RM instabilities

Energy release vs time:
front 0.4 ns, duration 3 ns



Density ratio	ρ_3 / ρ_4	A
Small	1.41 / 0.94	0.2
Middle	1.41 / 0.3862	0.57
Large	1.41 / 0.036	0.95

λ = 200 mkm и A = 20 mkm



Concentration distribution in third (blue) and forth (pink) regions for middle density ratio taking into account density gradient. Time moments from left to right 40, 80,120 ns. Size in millimeters

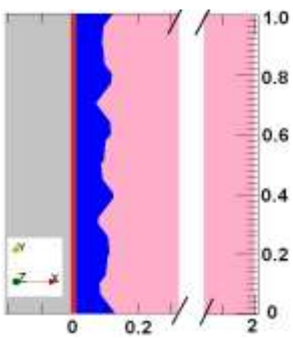
Spikes and bubbles have similar size and shape regardless the shape of disturbance peaks: smooth or sharp. Flow structure is regular

Prediction for E = 2 kJ
RT-RM instabilities

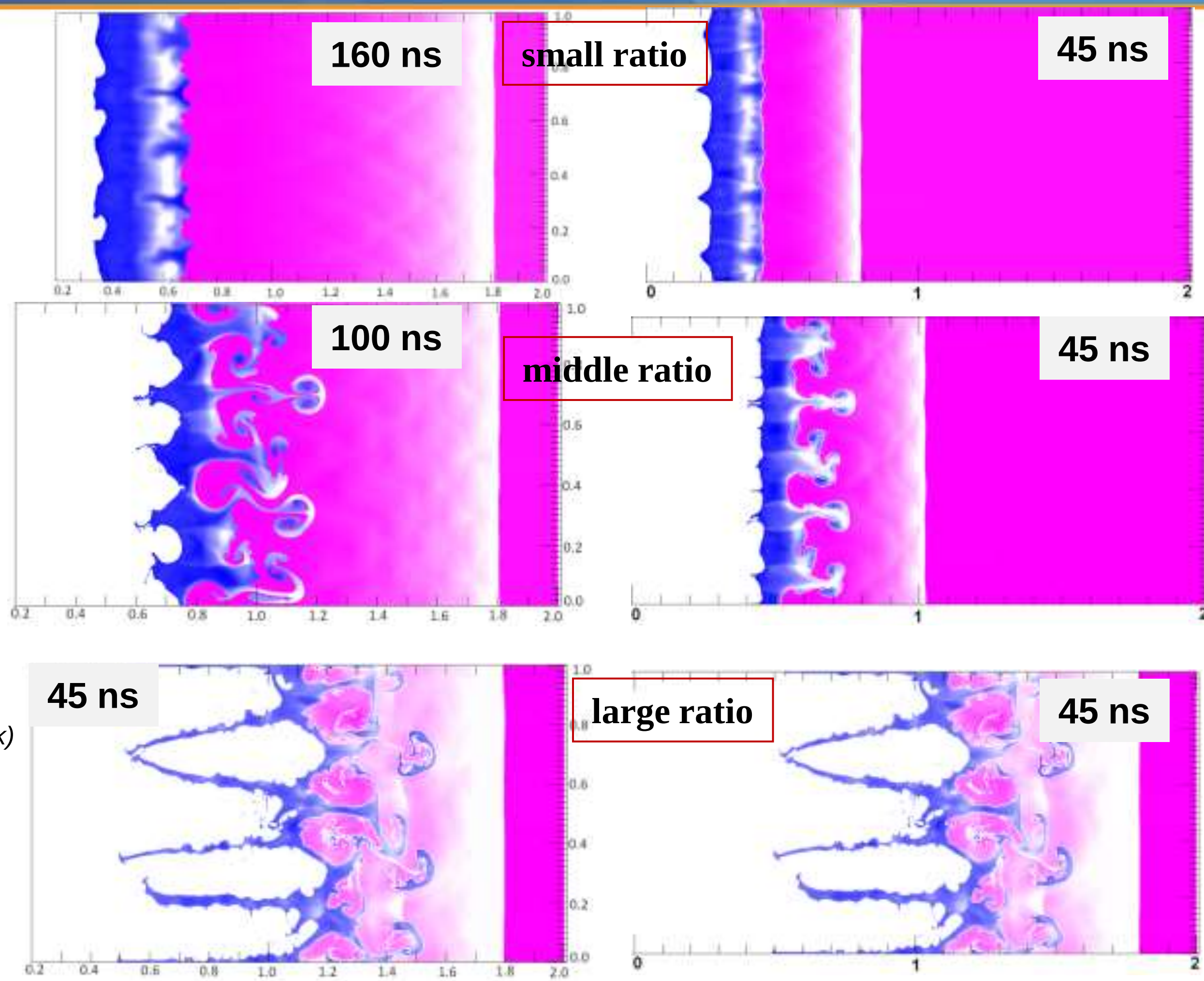
Disturbance: superposition of two saw-tooth wave:

1) λ_1 = 200 mkm, a_1=20 mkm
2) λ_2 = 128 mkm, a_2 =10 mkm

Initial interface



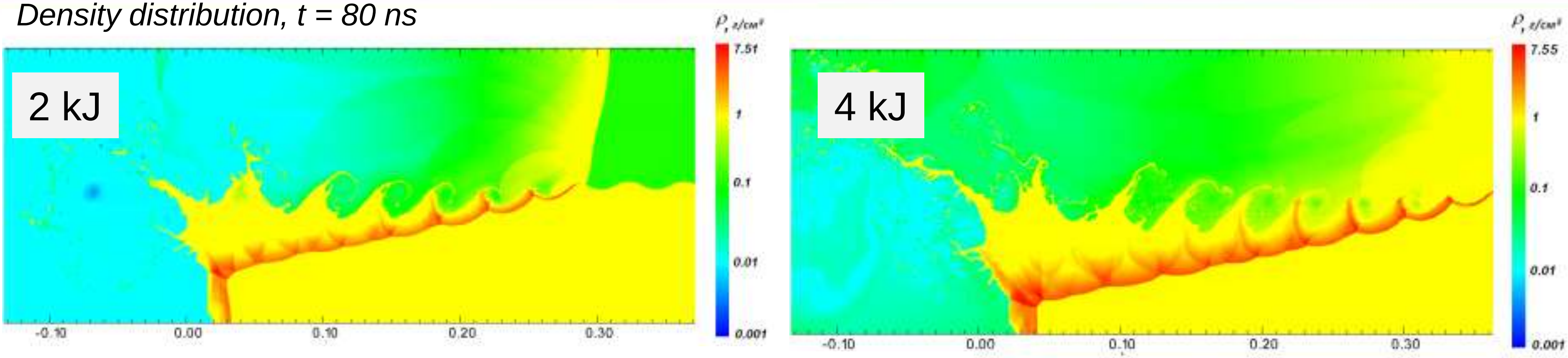
Concentration distribution in third (blue) and forth (pink) regions for small (top), middle (center), large density (bottom) ratios taking into account density gradient. Time moments correspond to SW front location x = 1.8 мм: 160, 100, 45 ns. Size in millimeters



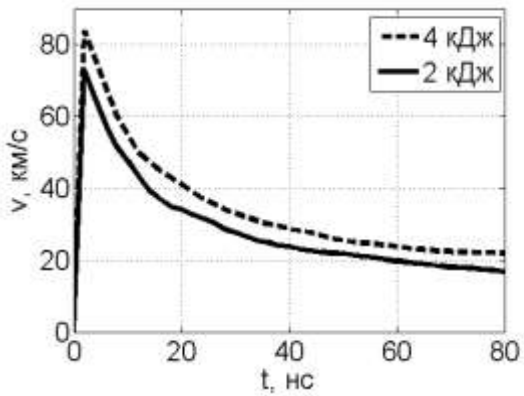
Increasing density ratio leads to rapid growth of instability development on interface. In the case of large density ratio the plastic shell is divided into separate fragments.

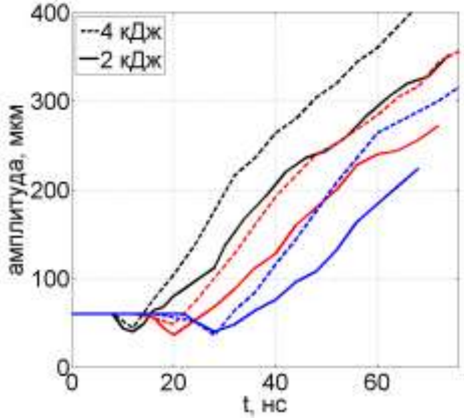
Prediction for E = 2 kJ
KH instability

Density distribution, t = 80 ns



SW velocity





Peak-to-valley height vs time
2^{ns} rollup (black),
3rd rollup (red) and
4th rollup (blue).

2 kJ data (solid line) shift to the left along time axis to match moments of interaction of SW and correspond rollup

In the case of 2 kJ SW velocity is 20% less than in the case of 4 kJ. Deceleration rate conserves.
For that reason RH instability has lower growth rate.
BUT! Total flow is typical for high level KH instability.

Conclusion

Code FOCUS describes development of hydrodynamic instabilities correctly;

Laser pulse energy 2 kJ is enough to instability investigating at different density ratio on interface

It is time to
discuss in details new experiments

Thank you