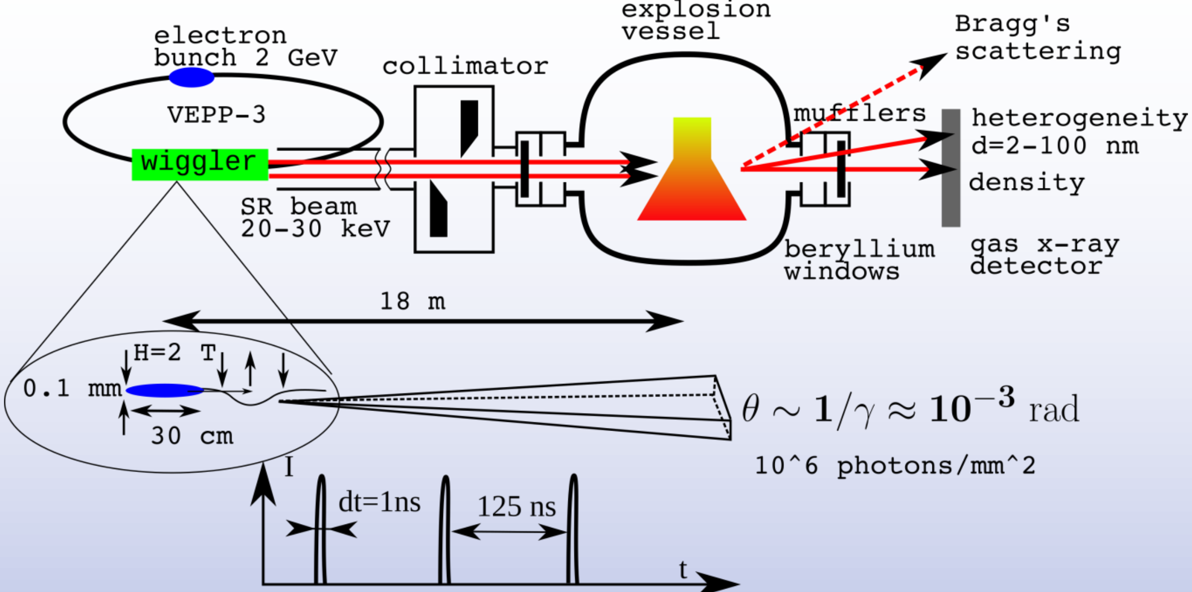
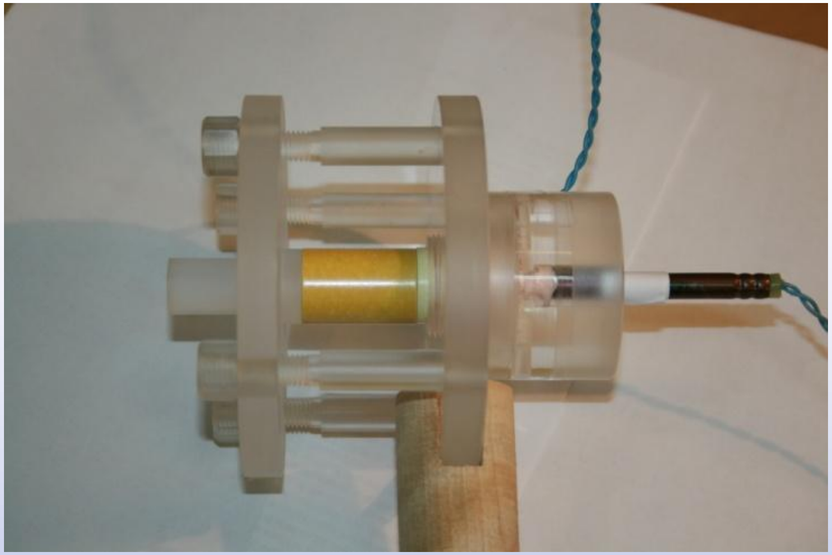
The using of SR for detonation and shock waves phenomena

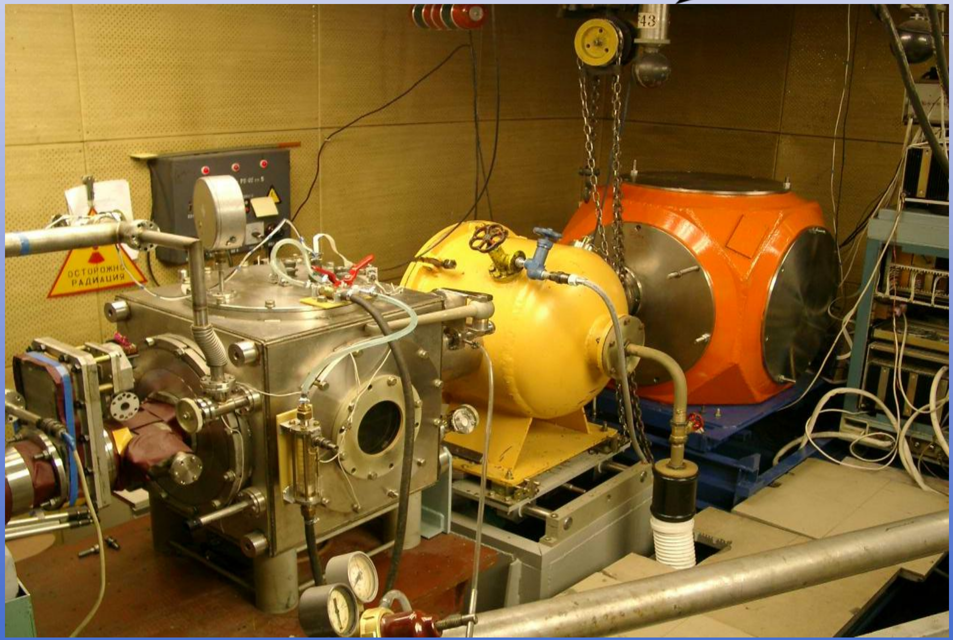
Institute of hydrodynamics SB RAS ***E.R. Pruuel, K.A. Ten, A.O. Kashkarov, I.A. Rubtsov, V.M. Titov***
Institute of solid state chemistry and mechanochemistry SB RAS ***B.P. Tolochko***
Institute of nuclear physics SB RAS ***V.M. Aulchenko, L.I. Shehtman, V.V. Zhulanov***
http://ancient.hydro.nsc.ru/srexpl

- Parameters of experimental station on VEPP3/VEPP4.
- High velocity x-ray radiography of detonation and shock waves.
- Tomography of mechanical parameters of detonation wave.
- Carbon condensation at detonation wave.
- Detonation synthesis of metal particle for catalysis.
- Investigation of nanothermites.

Experimental scheme and photos of station on VEPP3/VEPP4



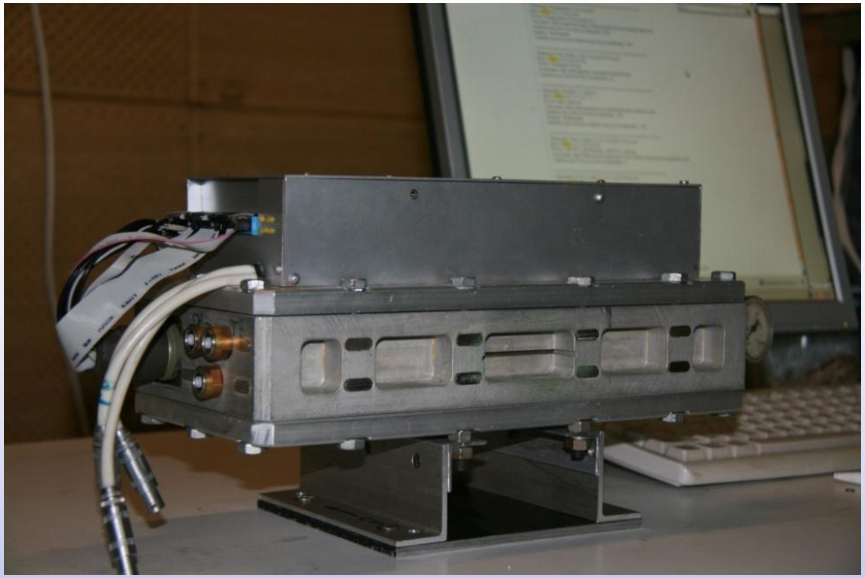




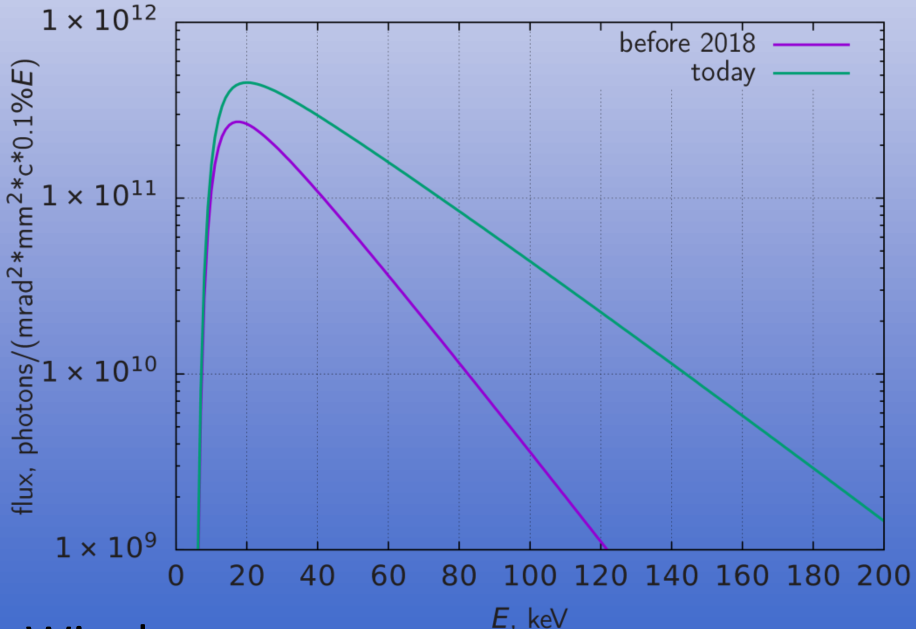
1999 г. Explosive mass 20 g. Time per frame 500 ns (today 125 ns). E_{ef} = 20 keV.

2013 г. Explosive mass 200 g. Time per frame 600 ns. E_{ef} = 40 keV.

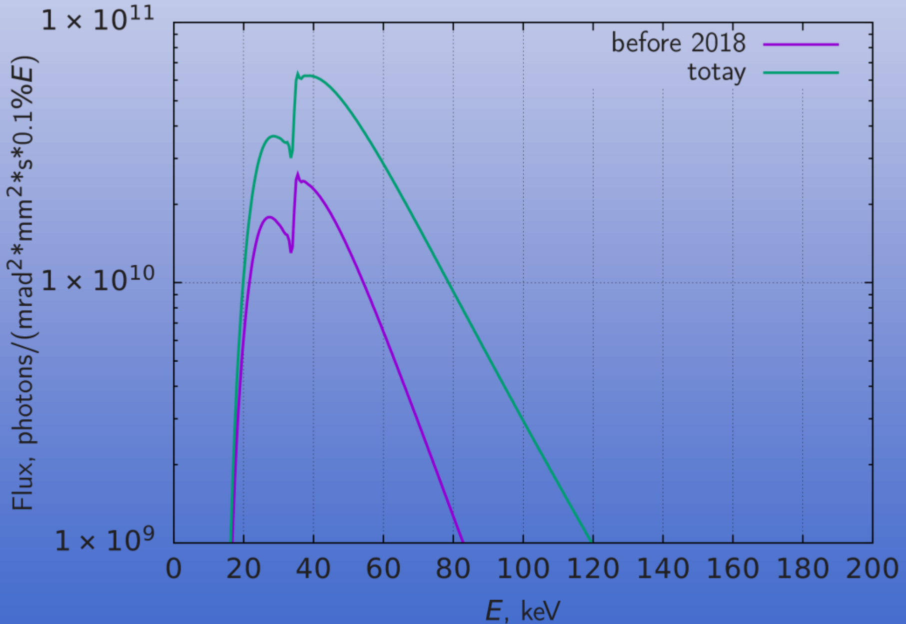
Microstrip gase detector for imaging of fast processes (DIMEX)



Appearance of the detector DIMEX-3.
Strip step is 100 mkm,
Number of spatial channels is 512,
Number of frames is 100,
Minimum time between frames is 125 ns.

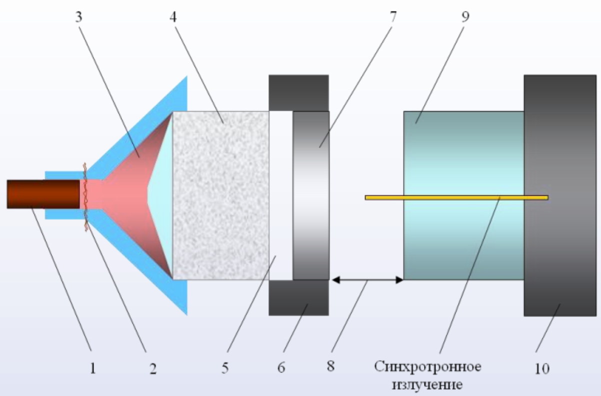


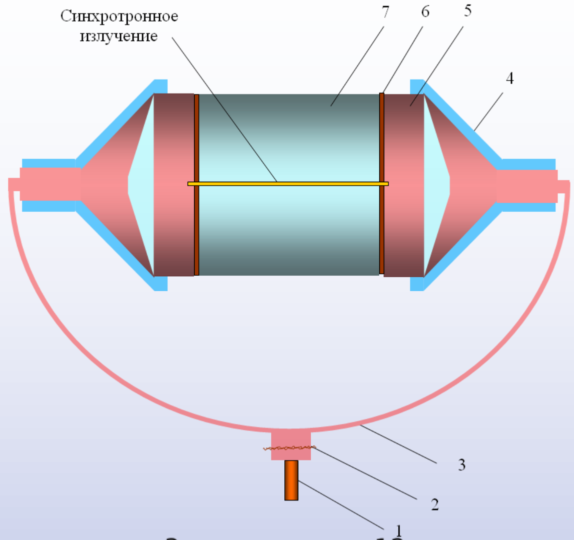
Wiggler spectrum.

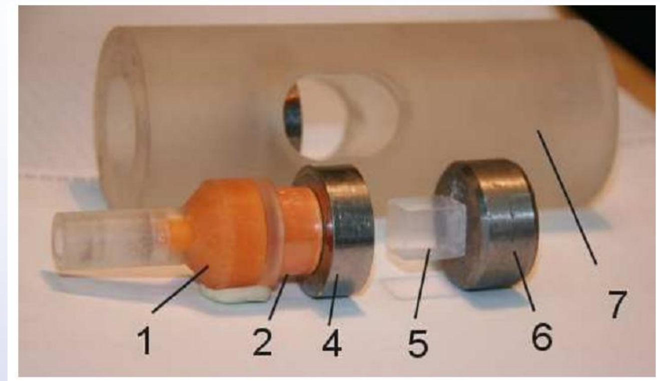


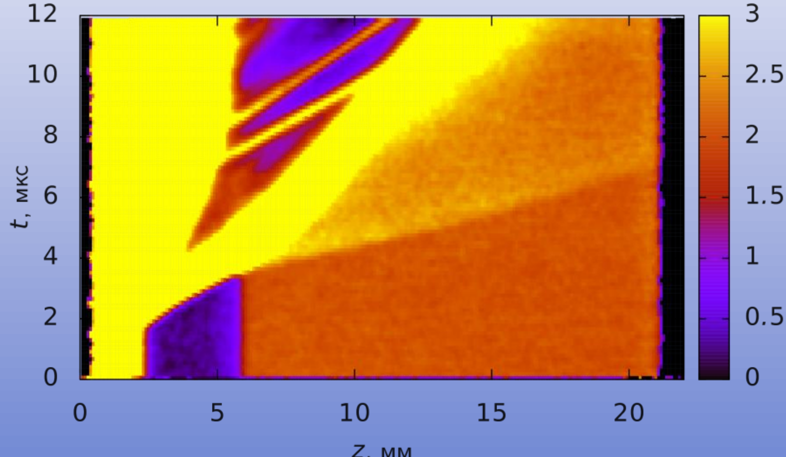
Final effectivity (wiggler, sample and detector).

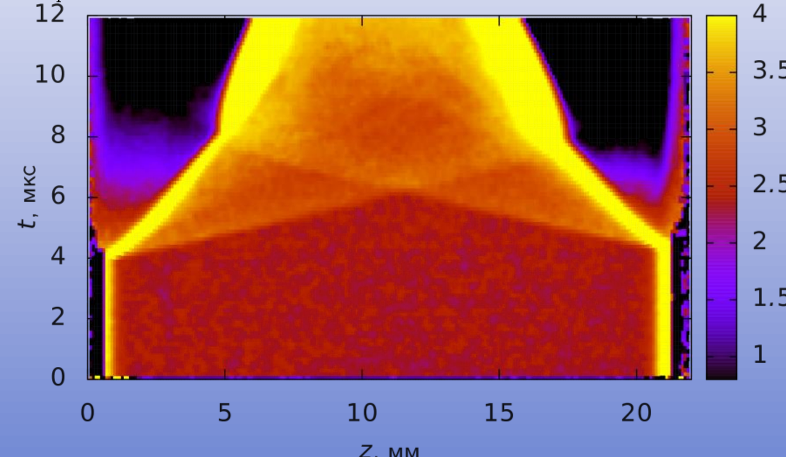
Shock wave experiments





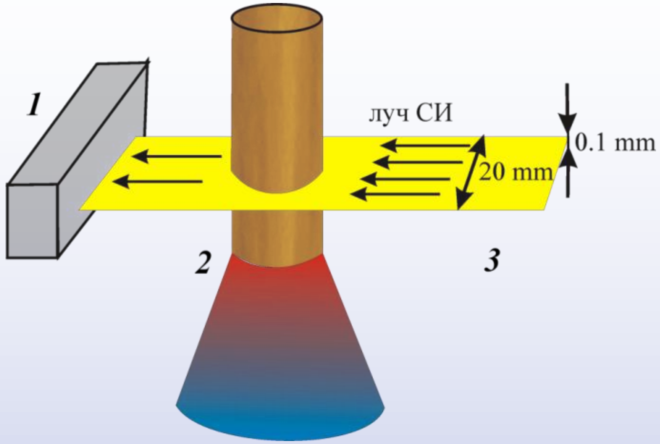




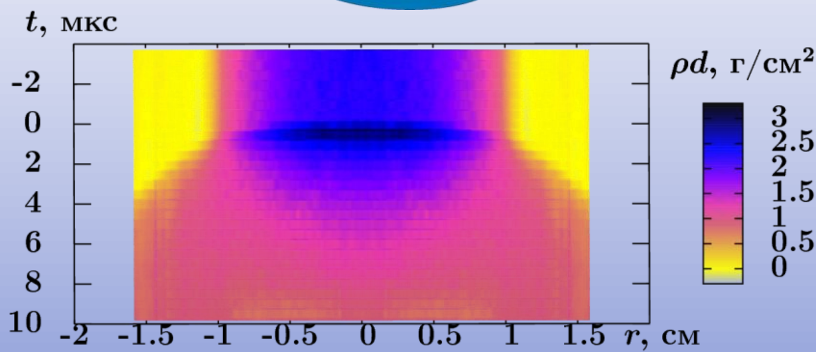


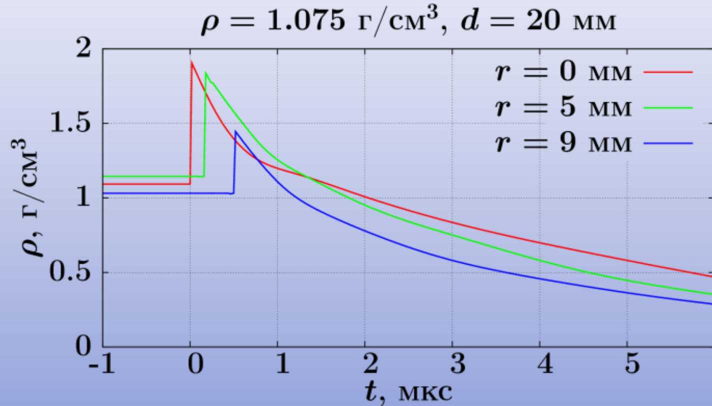
Shock wave investigation: 1 – explosive lens, 2 – main charge, 4 – guard ring with a thrown metal drummer (1 - 3 km/s), 5 - tested sample (0.1 - 2 g/ cm^3), 6 - base, 7 - centering guide.

High speed x-ray tomography

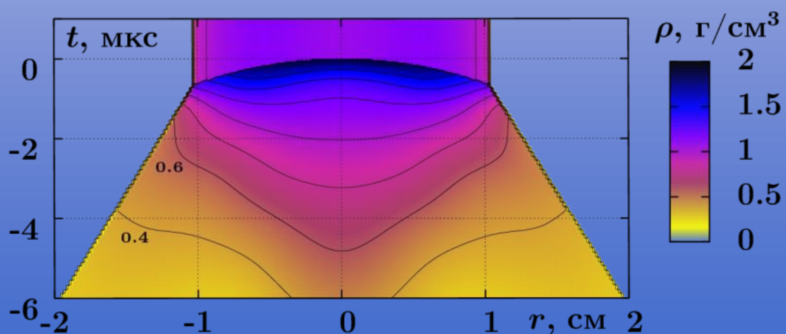


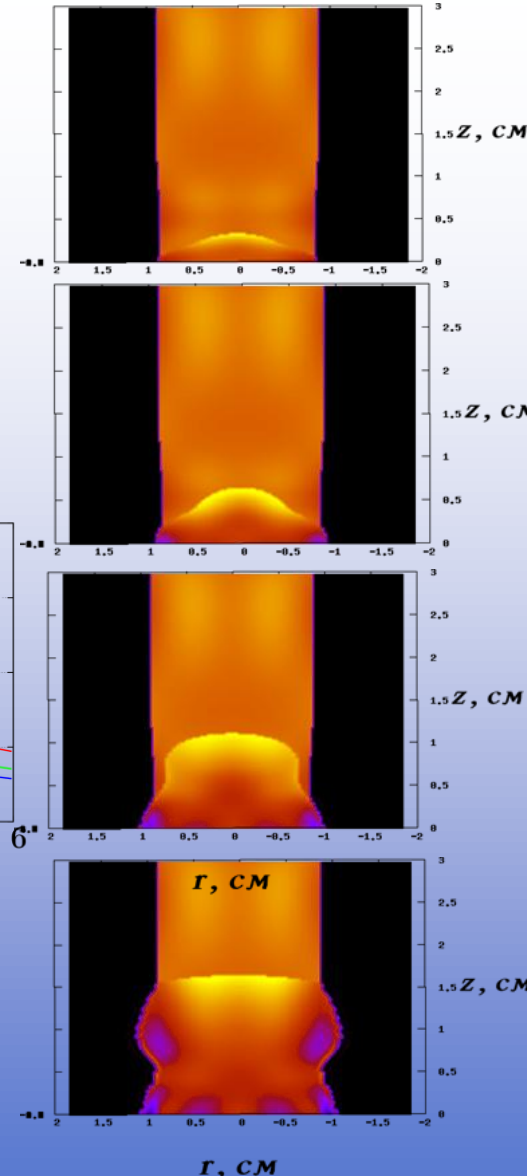
Scheme of tomography experiment for density distribution reconstruction: 1 – detector for transmitted and attenuated x-ray radiation, 2 – investigated cylindrical sample, 3 – x-ray beam.





Detonation of emulsion explosive. X-ray shadow and density distribution.





Combustion to detonation transition in charge of porous petn. Density distribution at 2, 3, 4, 5 mks from initiation time.

Restoration of gas-dynamic flow parameters: density, pressure and mass velocity

Equations of gas dynamics for a flow with cylindrical symmetry

$$\frac{\partial r\rho u}{\partial r} + \frac{\partial r\rho v}{\partial z} = \frac{\partial r\rho}{\partial t},$$

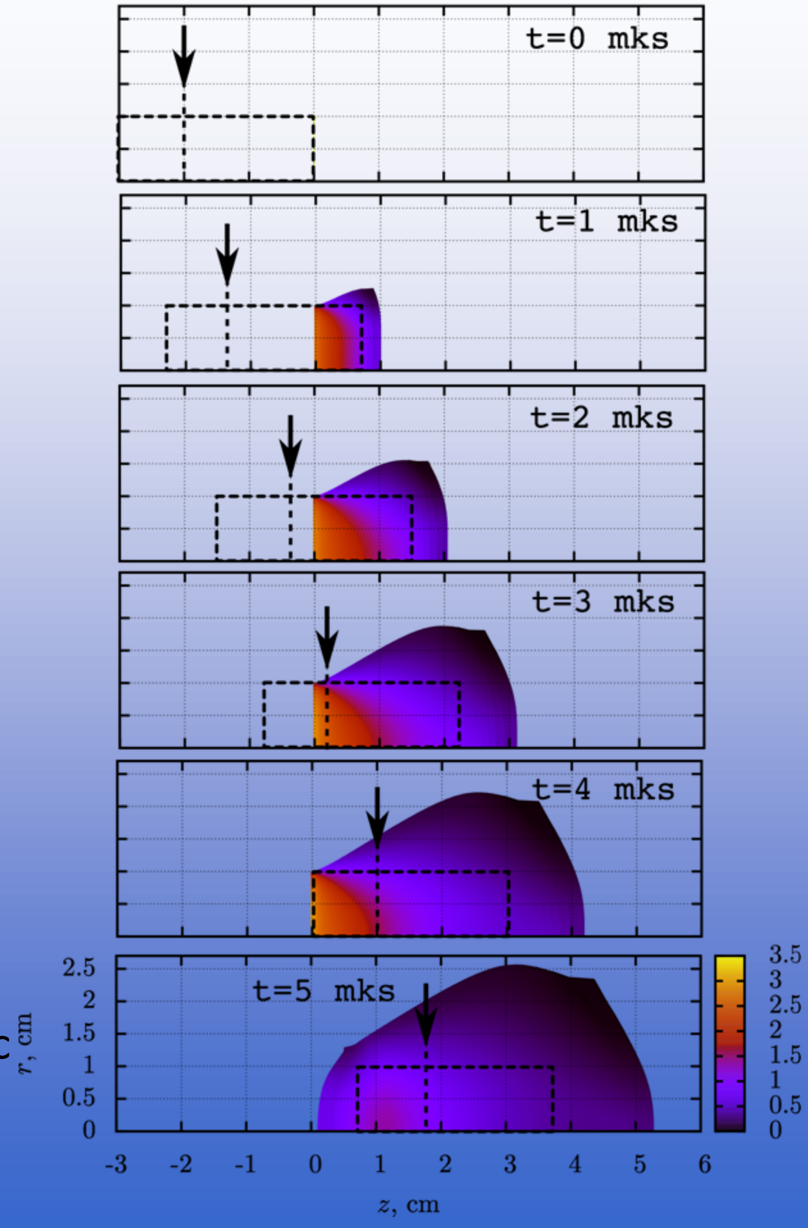
$$\frac{\partial r\rho u^2}{\partial r} + \frac{\partial r\rho uv}{\partial z} + r\frac{\partial p}{\partial r} = \frac{\partial r\rho u}{\partial t},$$

$$\frac{\partial r\rho v^2}{\partial z} + \frac{\partial r\rho uv}{\partial r} + r\frac{\partial p}{\partial z} = \frac{\partial r\rho v}{\partial t},$$

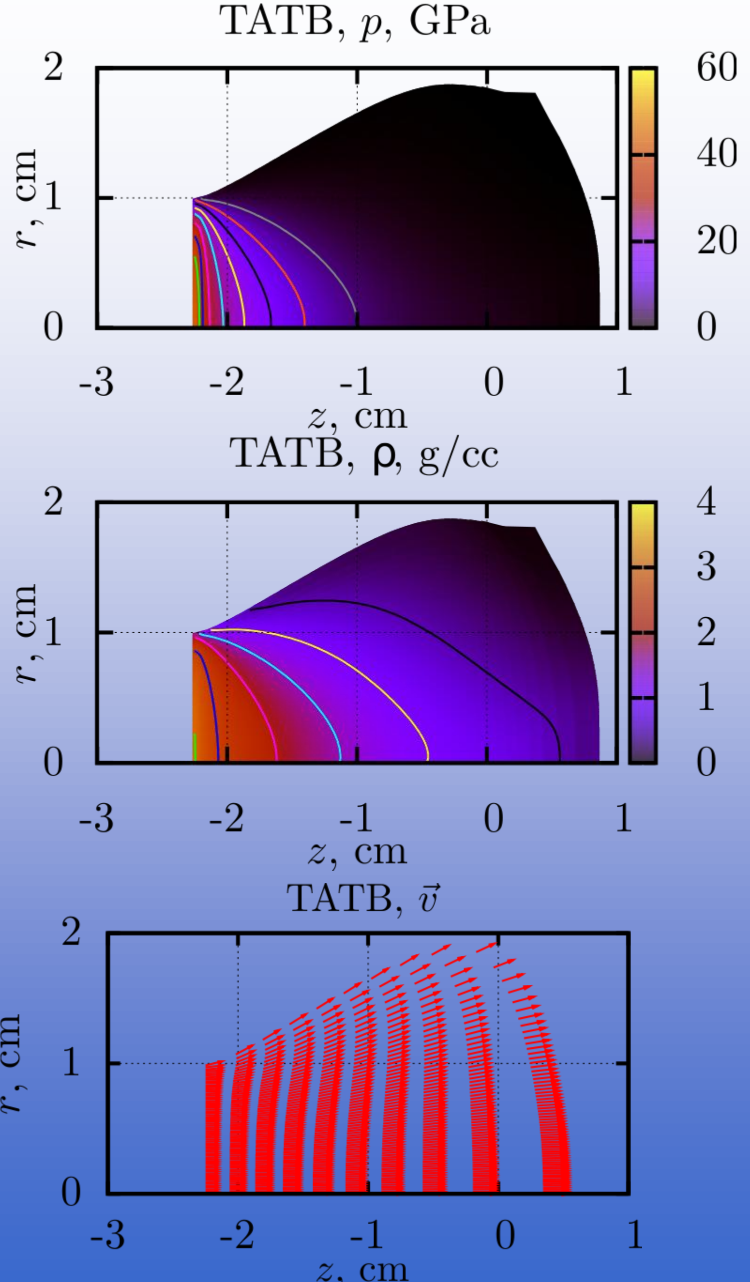
$$p(\rho) = p_0(\rho/\rho_{00})^{\gamma(\rho)}.$$

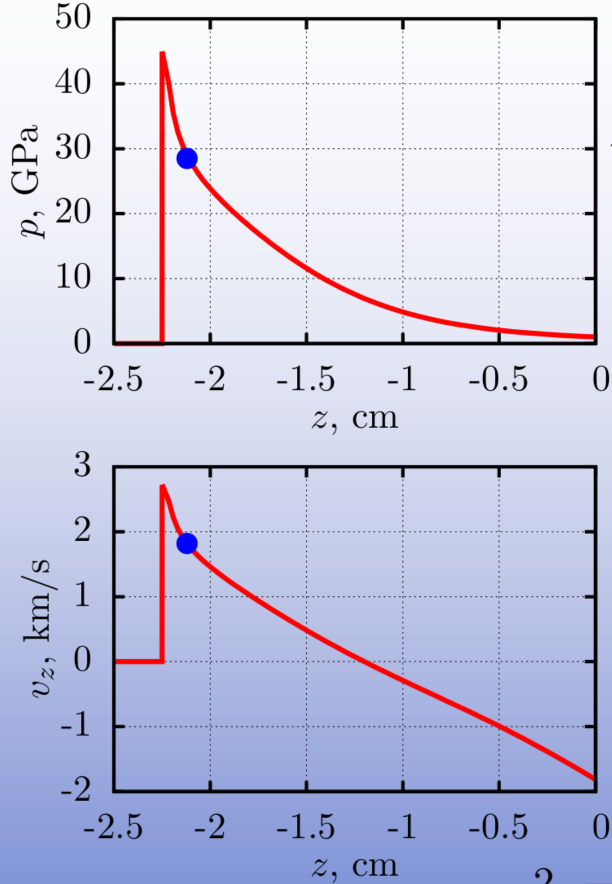
$\gamma(\rho)$ - the required dependence of the adiabatic exponent along the streamline.

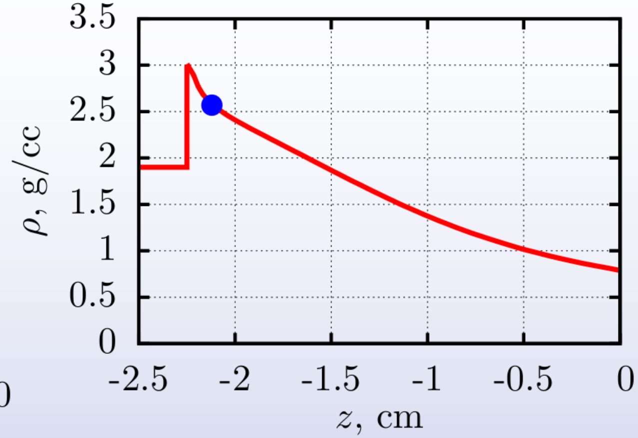
The problem is solved numerically by the Godunov method, in Lagrange coordinates, the discontinuity decays were considered in the acoustic approximation. The characteristic number of "adjustable" parameters 10, the characteristic number of flow computations 10^3-10^4.



Parameters of the flow during detonation of the charge of the TATB

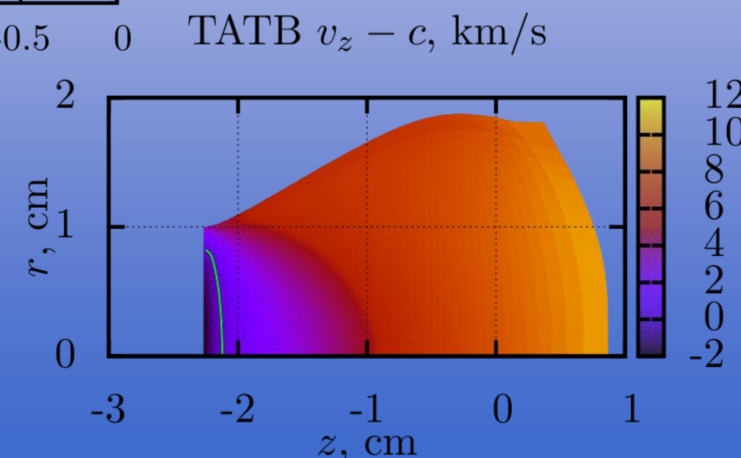






$$p(\rho)$$

$$c = (\partial p / \partial \rho)^{1/2}$$



X-ray scattering and Detonation synthesis of carbon nanostructures

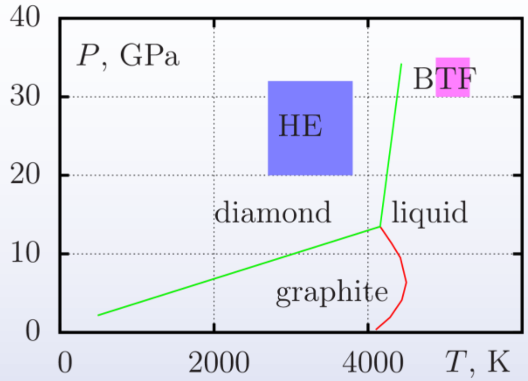
In the detonation products of a number of explosives, condensed carbon particles with a diverse phase composition are formed:

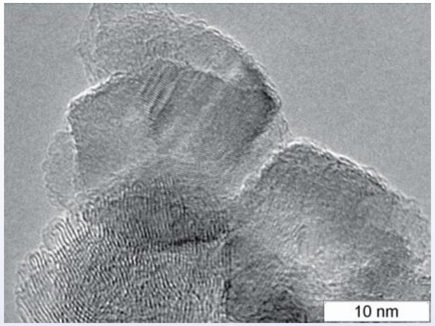
$C_7H_5N_3O_6$ – trinitrotolol (tnt)

$C_3H_6N_6O_6$ – hexogen (rdx)

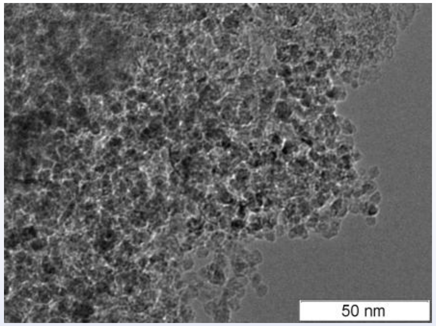
$C_6H_6N_6O_6$ – trimino trinitrobenzene (tatb)

$C_6N_6O_6$ – benzotrifuroxane (btf).

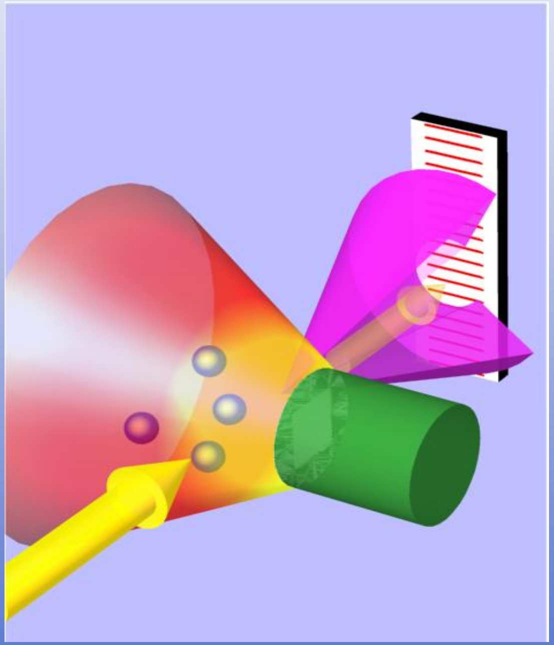


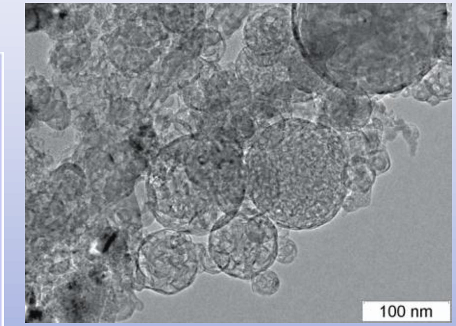


tnt

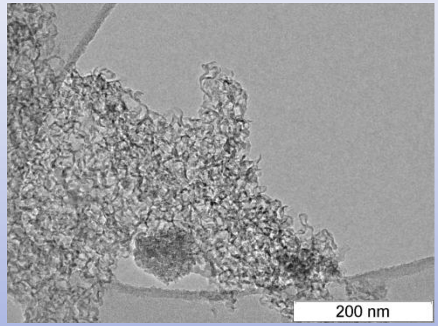


tnt + rdx (50/50)



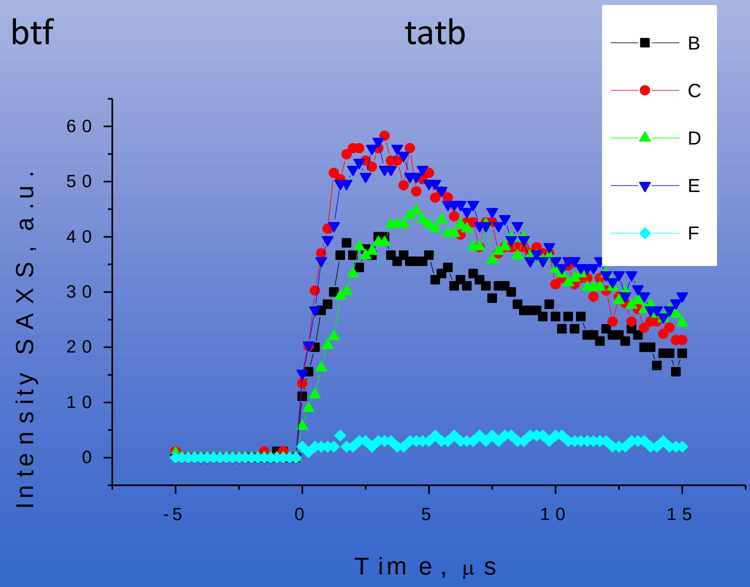


btf



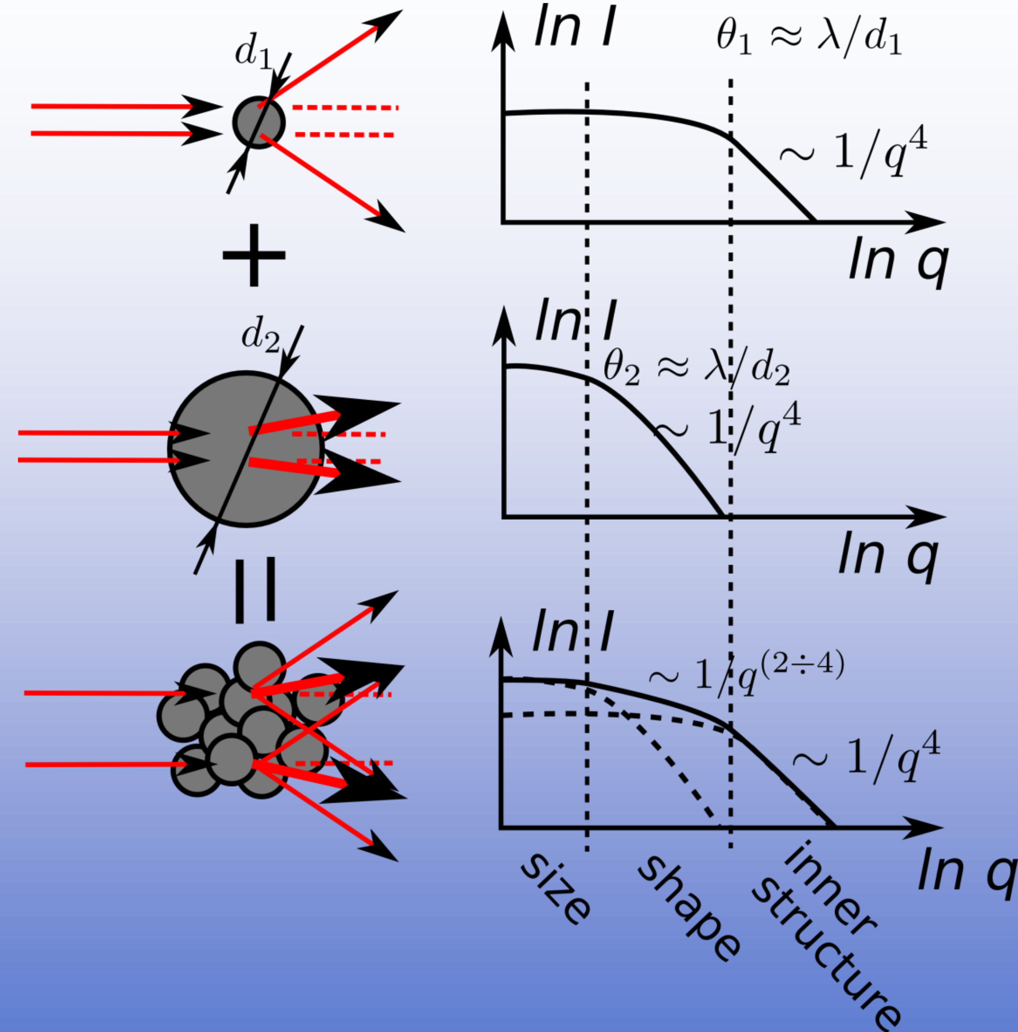
tatb

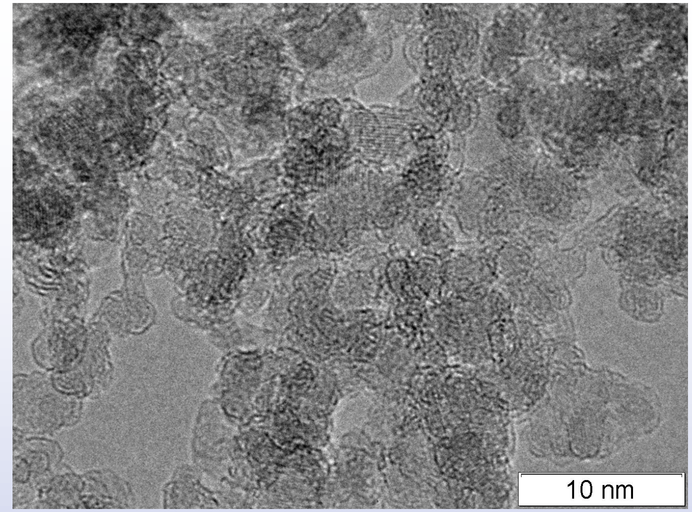
Yellow arrow - incident beam of SI, violet cone - X-ray scattering on carbon nanoparticles.



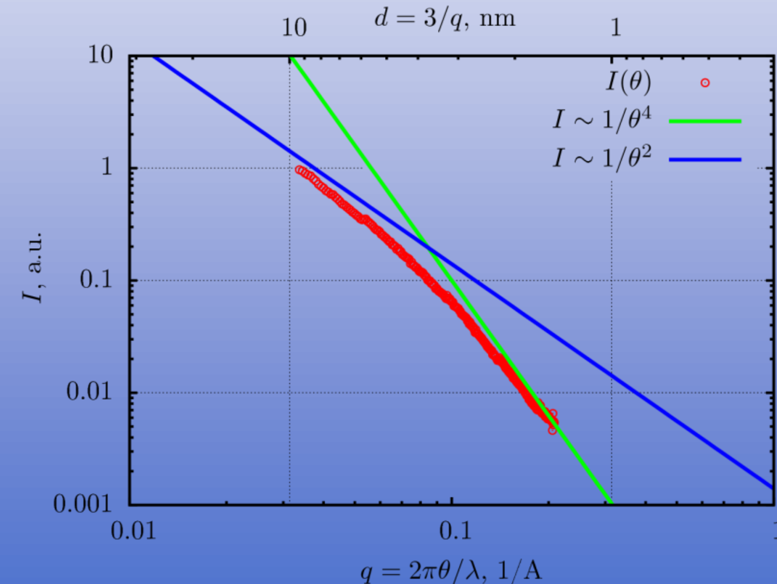
The method of small-angle X-ray scattering allows determining the parameters of the emerging particles in dynamics: B – tnt/rdx 70/30, C – tnt/rdx 50/50, D - tnt, E - tnt/rdx 60/40, F - rdx.

Reconstruction of the shape of nanocarbon structures





Detonation carbon.

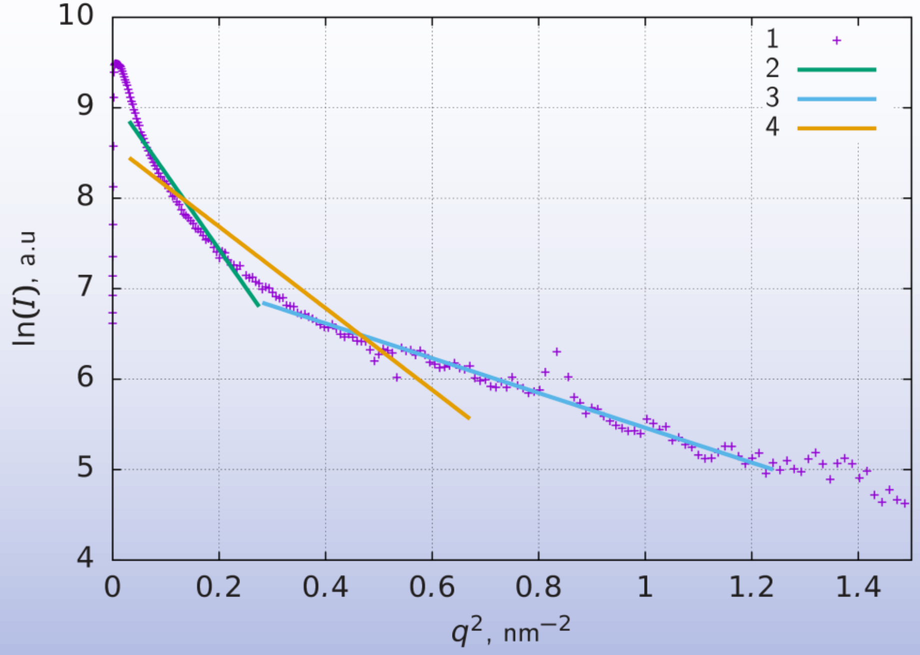


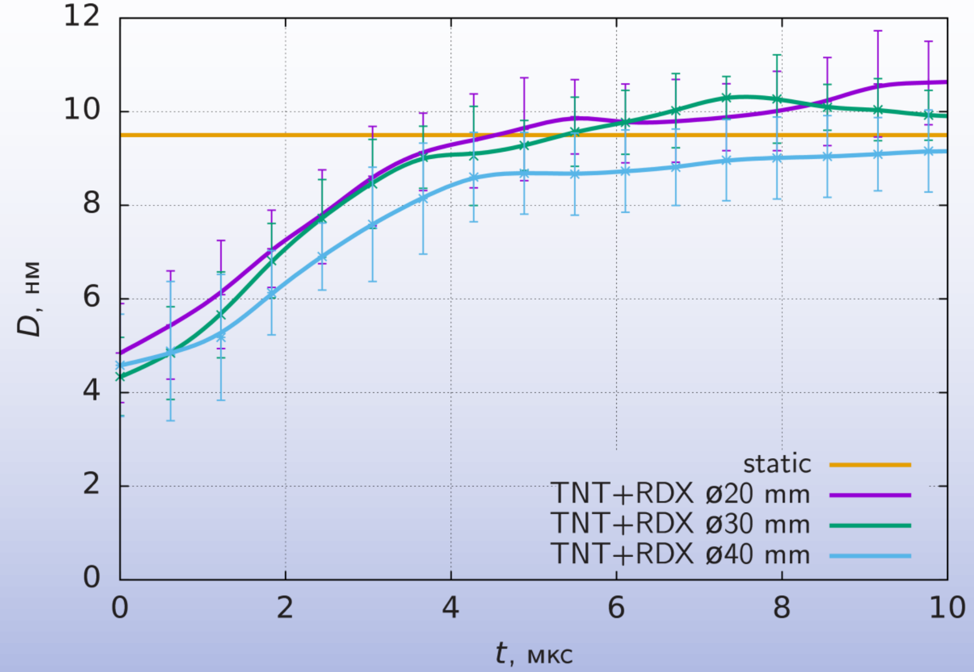
Simplified measurements

$$\theta \approx \lambda / d \quad I(\theta) \longleftrightarrow \Delta\rho(scale = \lambda/\theta)$$

Static mesurement of scattered x-ray from detonation carbon. Fractal structure and homogeneous particle.

Reconstruction of carbon particle size

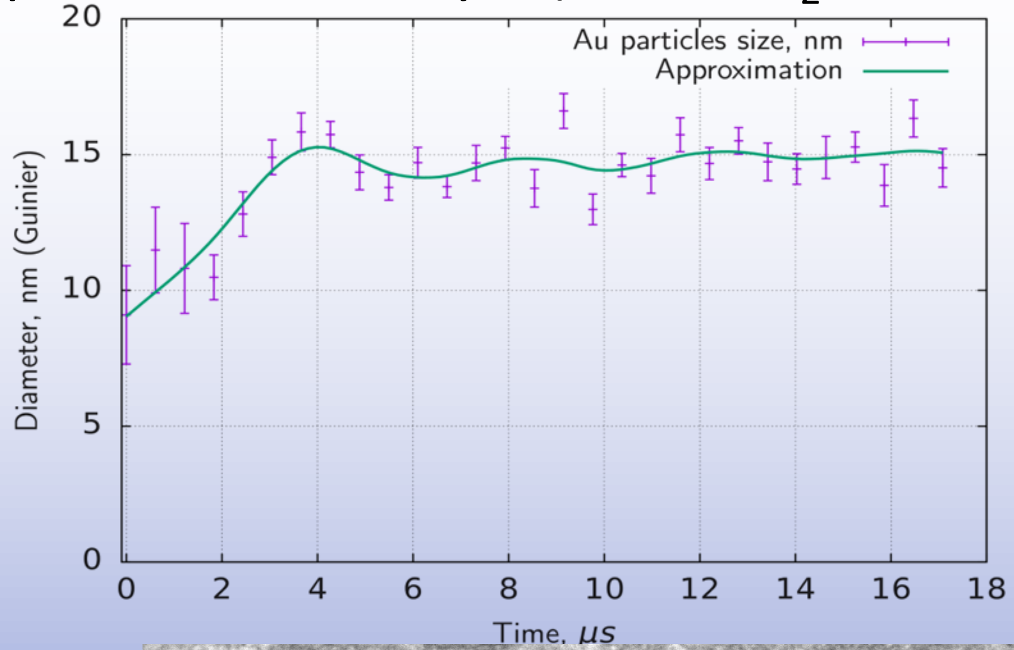


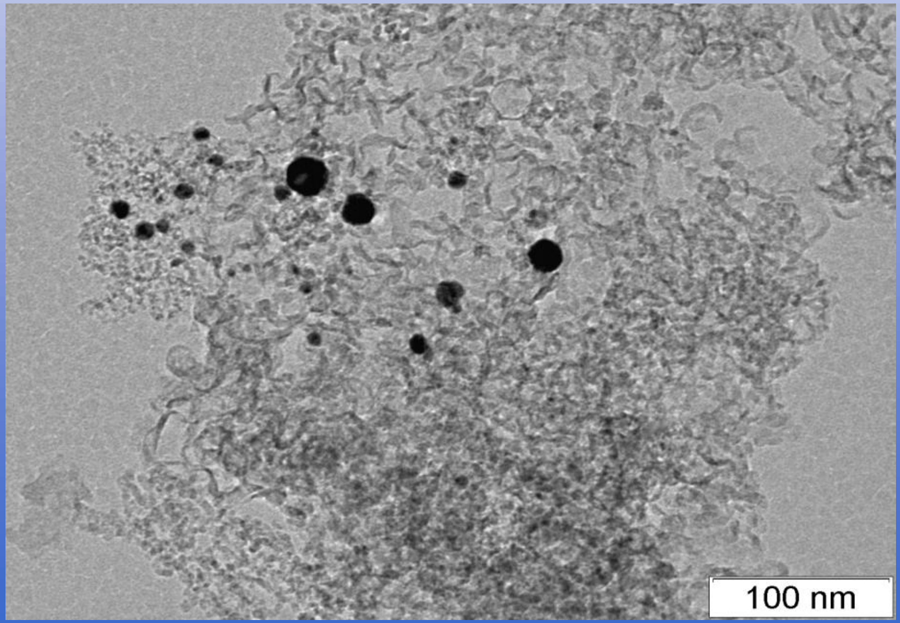


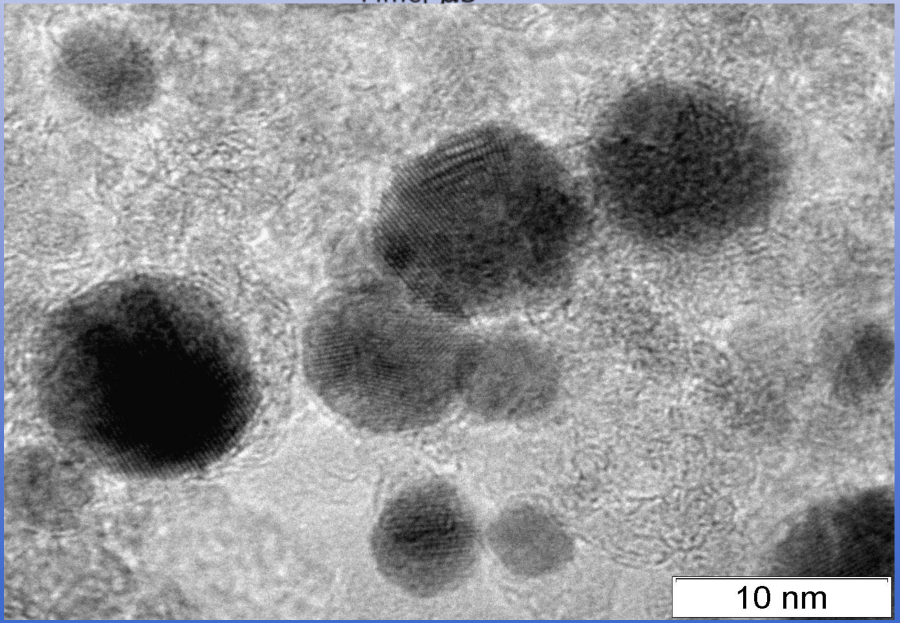
Static experiment. Guinier approximation for different scattering vector q ranges:
0.9-2.6 mrad D=13 nm;
0.9-4.1 mrad D=9.5 nm;
2.6-5.5 mrad D=6.2 nm.

Dynamics experiment for cylindrical charges of explosive with different diameter.

Detonation synthesis of metal nanoparticles for catalysis(CO to CO_2 oxidation)

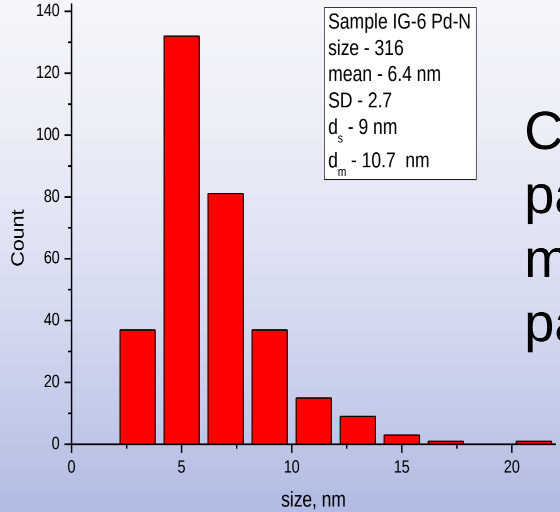






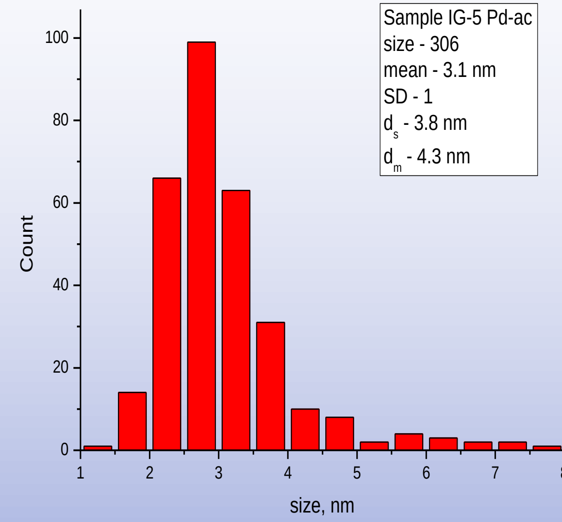
Particle size control.

Palladium nitrate ($Pd(NO_3)_2$).
C/Pd=0, D = 6.4 нм.

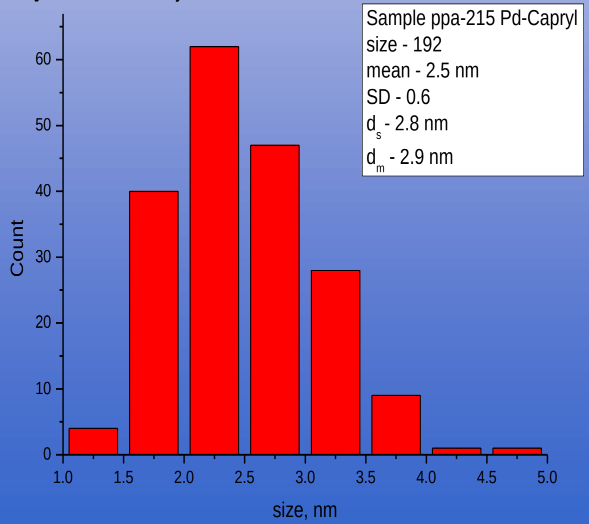


Compounds with a larger part of palladium in the molecule produce larger particles.

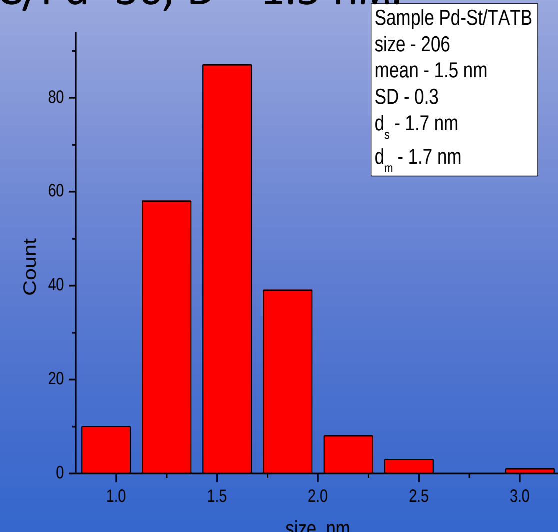
Palladium acetate ($Pd(O_2CCH_3)_2$).
C/Pd=4, D = 3.1 нм.



Palladium caprylate ($Pd(C_7H_{16}COO)_2$).
C/Pd=16, D = 2.5 нм.

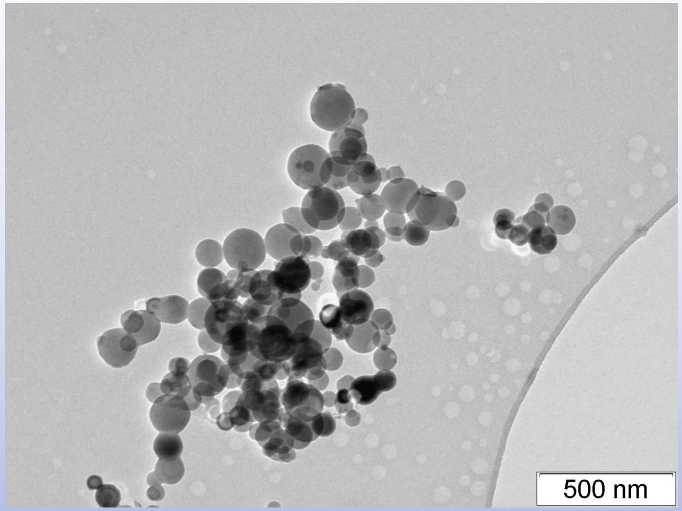


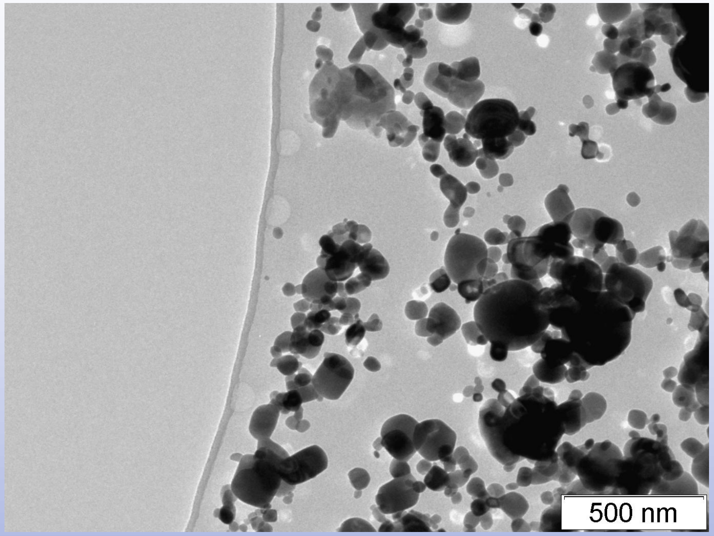
Palladium stearic ($Pd(C_{17}H_{35}COO)_2$).
C/Pd=36, D = 1.5 нм.

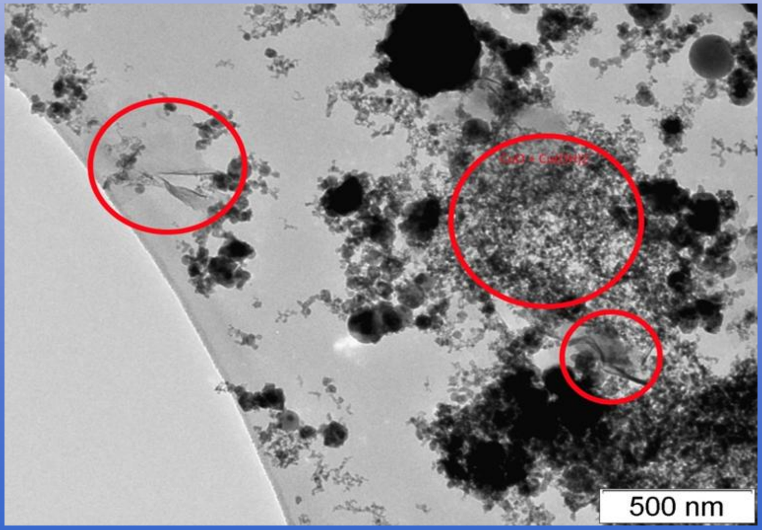


Combustion of nanothermic mixtures

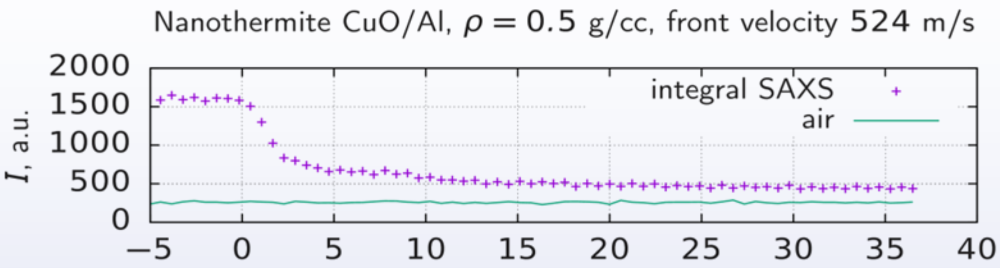
$2Al + 3CuO \rightarrow Al_2O_3 + 3Cu$

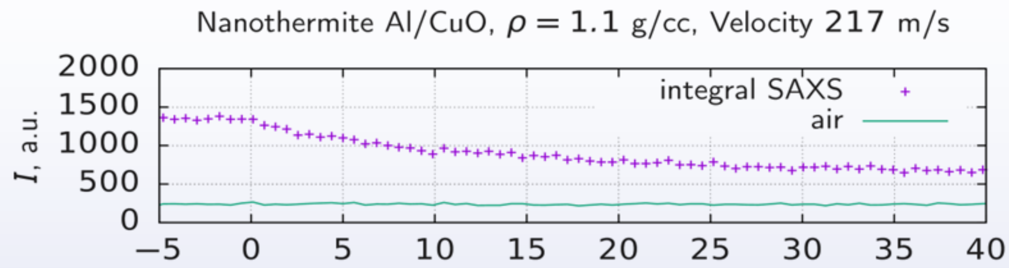


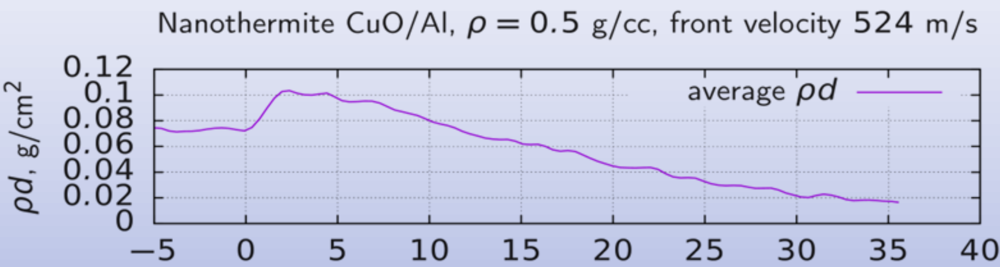


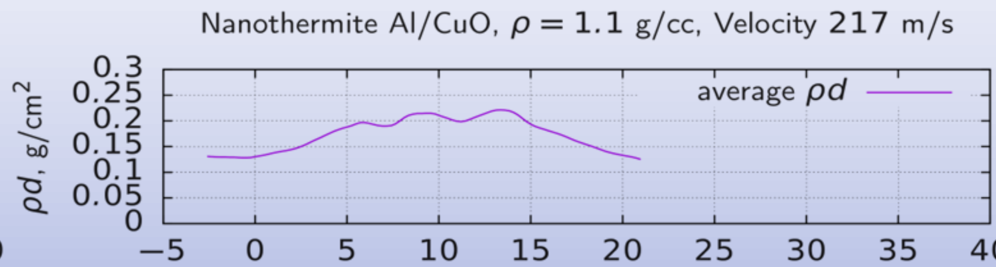


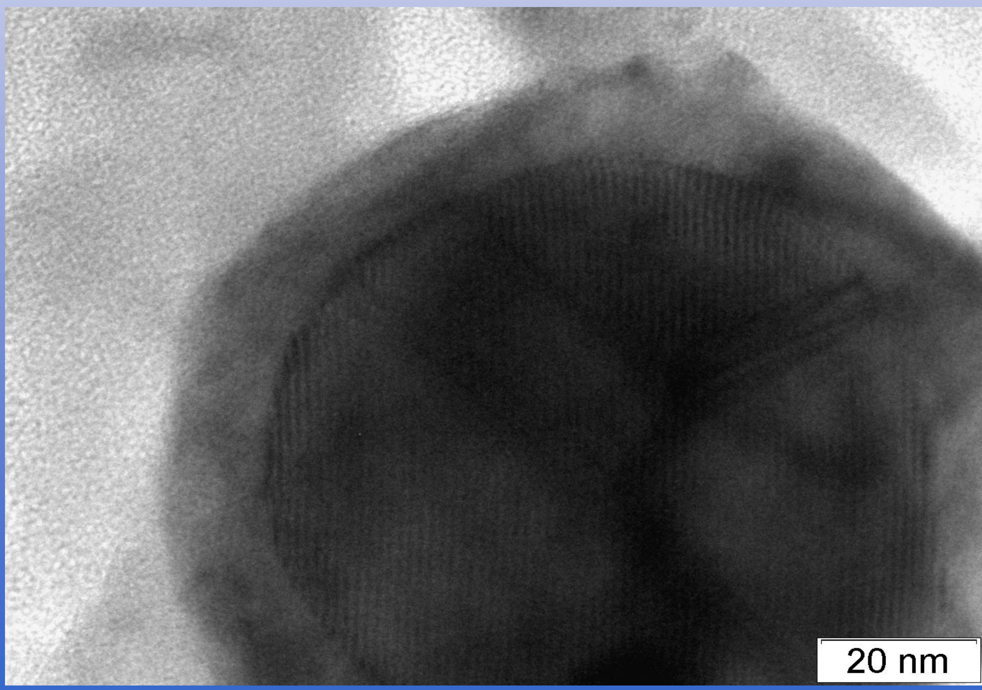
Scattering and density at thermite combustion

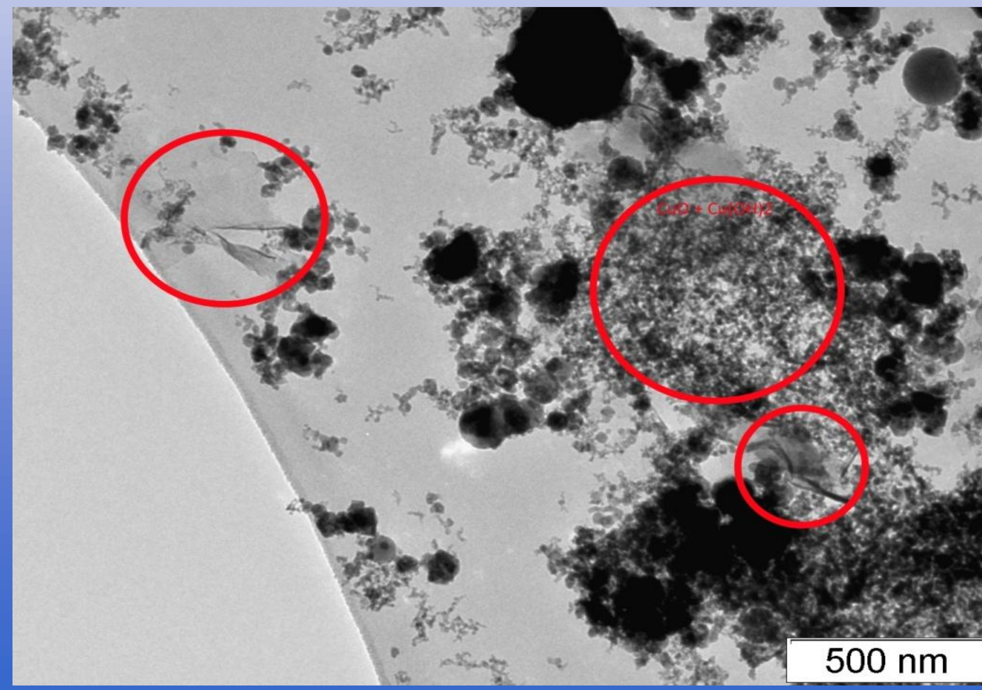




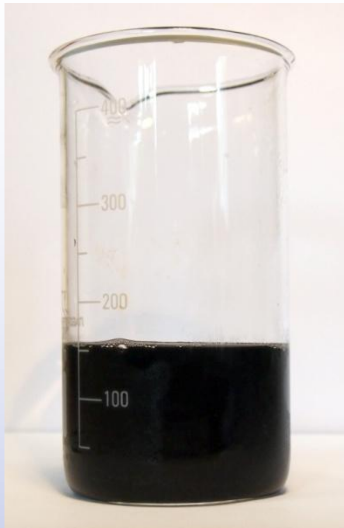




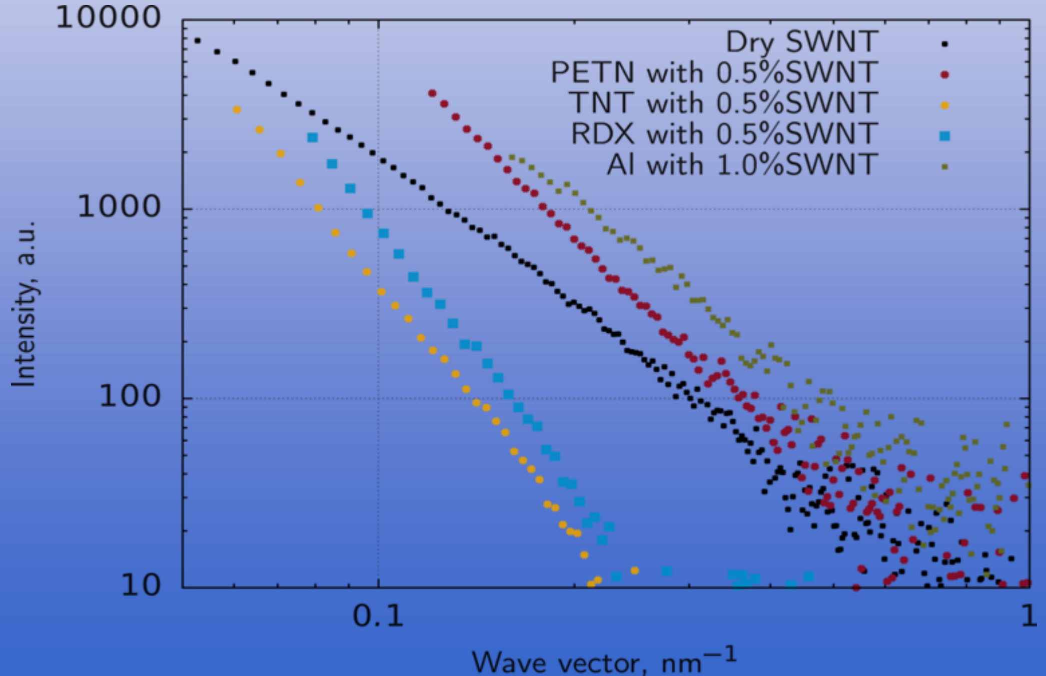


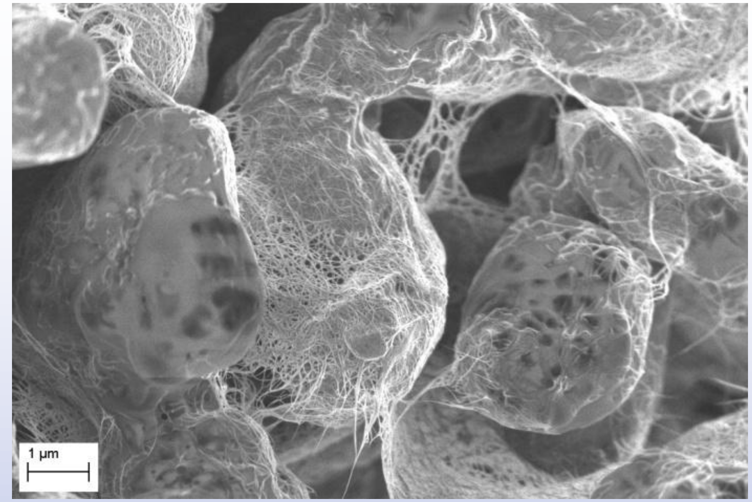


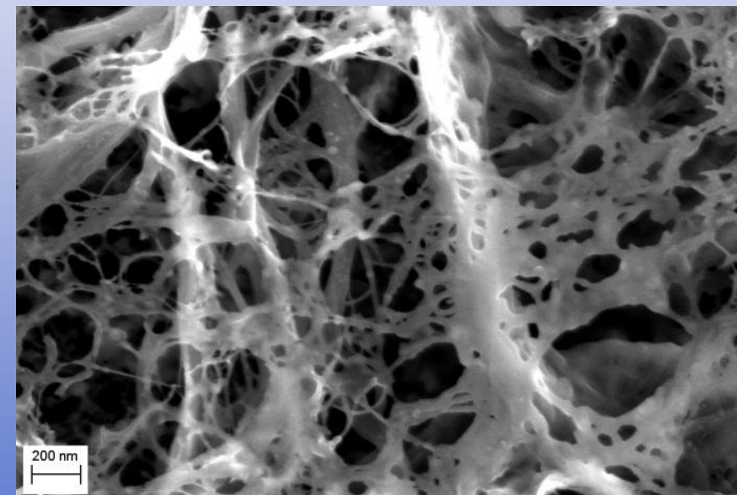
Modification of explosives by carbon nanotubes



A solution of TNT in acetone. + Carbon nanotubes dispersed in water = Nanostructured explosive.

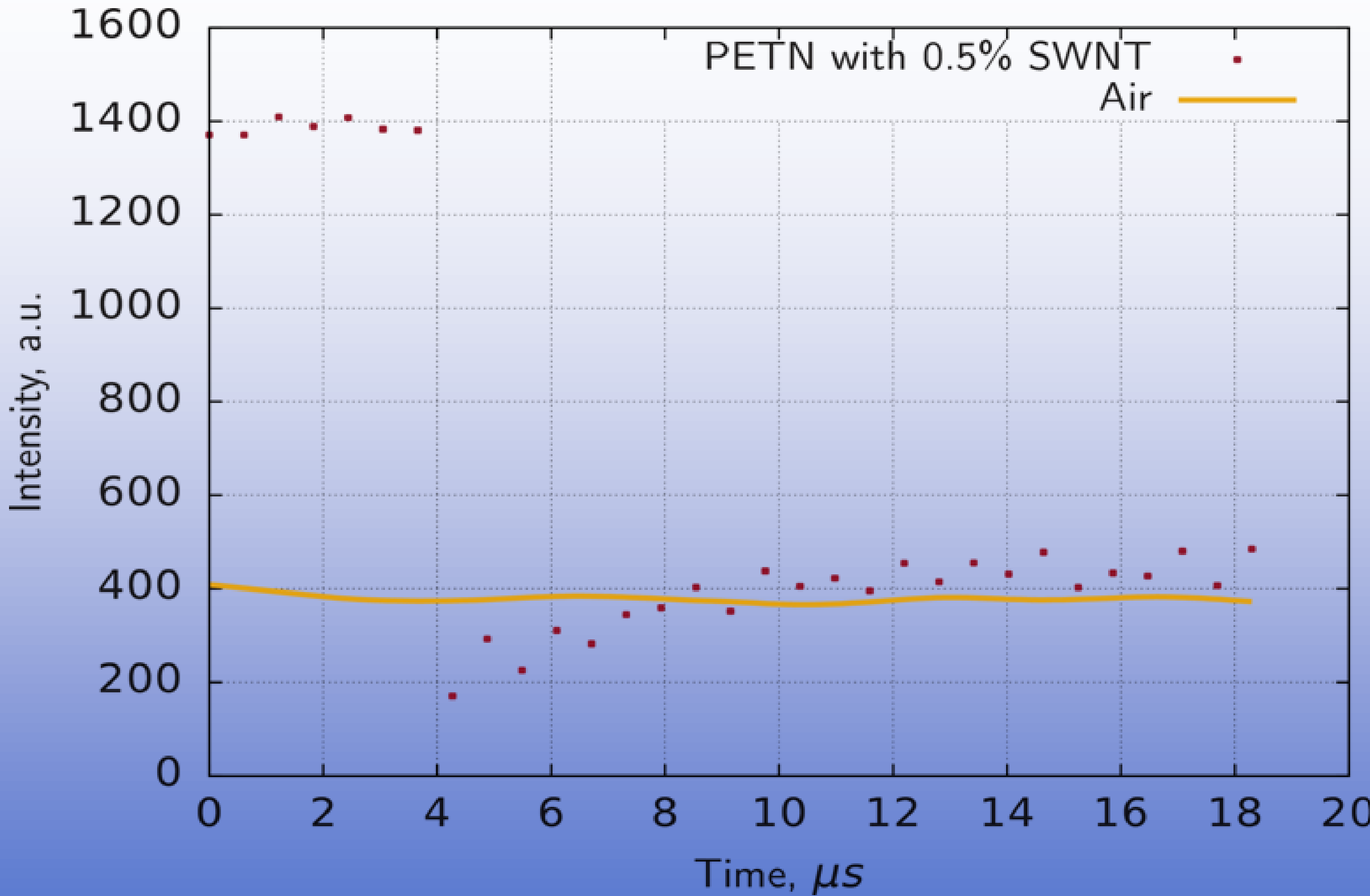






Nanostructured explosive.

X-ray scattering at detonation. Petn with single wall carbon nanotube.



Thank you
for your attention!

Благодарю
за внимание!