MWTA Efforts

N.G.Borisenko

devoted to the memory of Yu.A.Merkuliev

Moscow Workshop on Targets and Applications was started in 1997 by Yuriy Merkuliev the founder and the first head of the Thermonuclear target laboratory (TTL) in the P.N. Lebedev Physical Institute.

By that time the full range target activity existed in the Lebedev Institute

- 1997 – the 1st MWTA in Lebedev: scientists & engineers, self-made and commercial microshperes, foams, explosives, equipment for production and characterization, "battle between theorist and fabricator" ,T, FST met.
- 2002 – ECLIM+2nd MWTA in Presidium of RAS: BeDT, direct-indirect proposals, experimental demonstration of new materials handling and properties
- 2007 – the 3rd MWTA in LPI: shot experiments begun. HiPER program

4th MWTA in the presence of TFW and target network is distributed all over ECLIM (Nazarov, Koresheva and others). Review by I. Prencipe about August network meeting is to follow.

- Working for Targets and their Applications in the TTL LPI RAS

New experimental forces joined:

Prof. V.A.Davankov and Prof. A.V.Pastukhov from Nesmeyanov Institute of Elementoorganic Compounds RAS

Dr. E.A.Kostrov and Prof. E.I.Demikhov (no photo) from LPI RAS

A.A.Shapkin from MSU and LPI RAS

Tsyurupa M.P., Blinnikova Z.K., Proskurina N.A., Pastukhov A.V., Pavlova L.A., Davankov V.A. Hypercrosslinked Polystyrene: The First Nanoporous Polymeric Material // Nanotechnologies in Russia. 2009. V. 4. N. 9–10. P.665–675

Mikhajlova, G. N., Aksenov, V. P., Antonova, L. K., Mikhajlov, V. S., Troitskij, A. V., Demikhov, E. I., ... & Lavrishchev, S. V. (2009). Long-term stability of superconducting Bi (2223) and Dy (123) taps in direct current circuit.

E.I.Demikhov, E.A.Kostrov RF Patent 2007133372/22 8

A.A.Shapkin, N.I. Chistyakova. The Mossbauer spectroscopy application for iron- and tin-containing nanoparticles. TFW5 poster

Thermonuclear target laboratory team at present:

- A.A.Akunets, I.V.Aleksandrova, N.G.Borisenko, A.I.Gromov, V.M.Dorogotovtsev, E.R.Koresheva, A.I.Nikitenko, I.E.Osipov, S.M.Tolokonnikov, T.P. Timasheva, A.S.Orekhov, E.I.Demikhov (Cryogenic Dep), E.A. Kostrov (CryoDep), I.V.Akimova (QRD), L.A.Borisenko (MSU), A.V.Pastukhov, V.A.Davankov (INEOS), V.G. Pimenov (IOC RAS), E.I.Sheveleva (IOC RAS), A.A. Shapkin, O.E.Ivanisova, K.A.Pervakov, E.I.Tarakanova
- Coworkers from N.D.Zelinsky Institute of Organic Chemistry, Nesmeyanov institute of Elemento-Organic Chemistry, M.A.Prokhorov Institute of General Physics, Moscow State University, Moscow Engineering Physical institute (MEPhI)

Different facilities now consume variously configured structured targets instead of foams of 90s.

- The form of washer in the center is “standard” for LPI (largest probability to do sample)

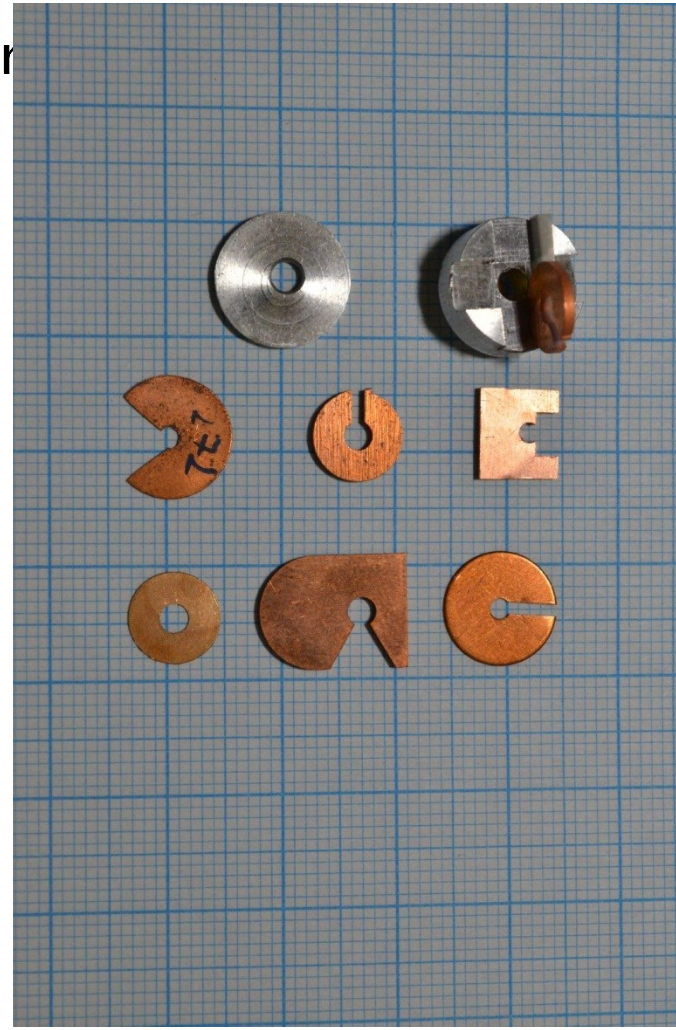
Different opportunities:

Alternative fuel

Density gradients

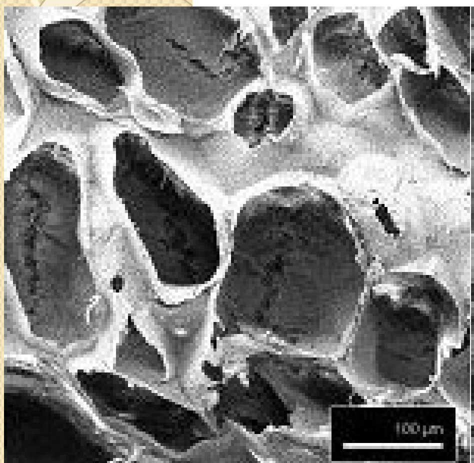
Nanostructured layers

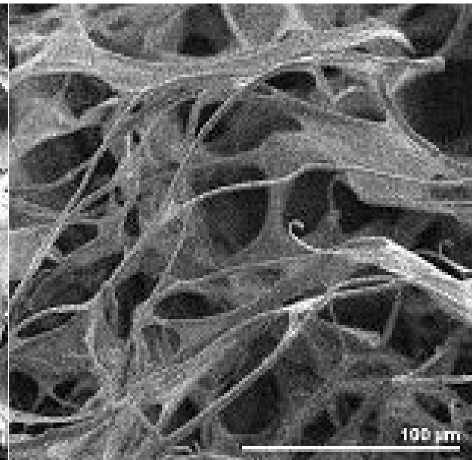
Burning shells

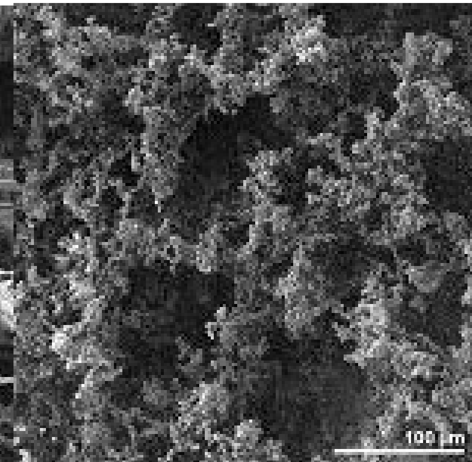


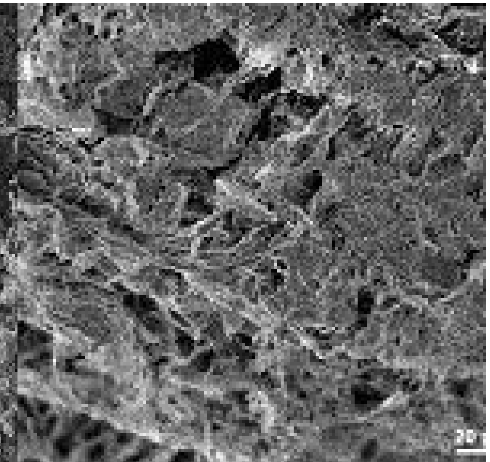
Microstructured materials

(foams, thread structures, snow-like, 3D net, aerogels)







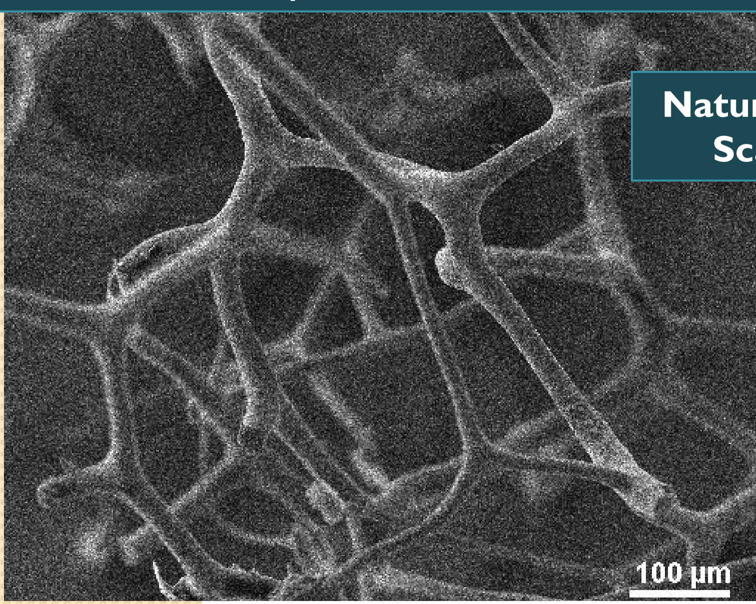


Agar-agar
Scale: 100 µm

Collagen
Scale: 100 µm

Polyvinylformal
Scale: 100 µm

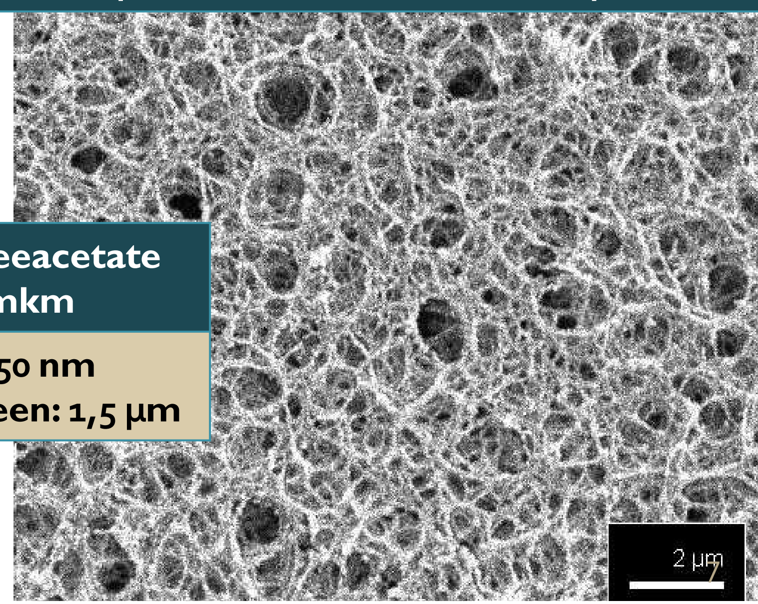
PET
Scale: 20 µm



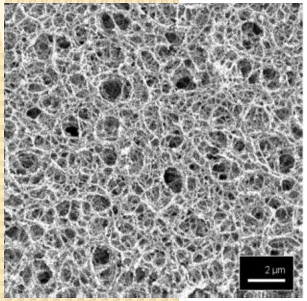
Natural sea sponge
Scale: 100 µm

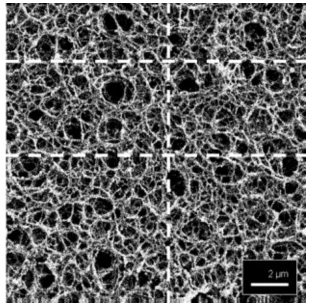
Cellulose Threeacetate
Scale: 2 mkm

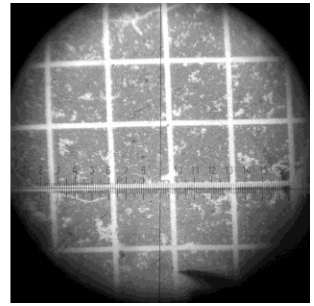
Wire dia: 50 nm
Distance between: 1,5 µm

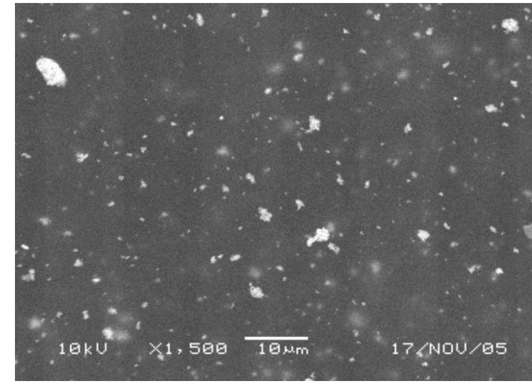


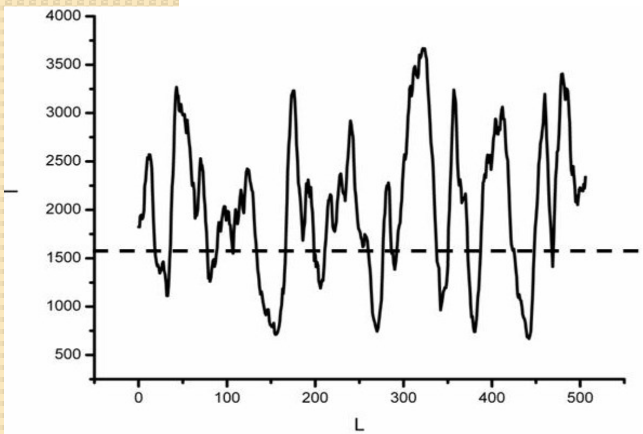
Characterization of pure CTA foam and that with Cu nanoparticles



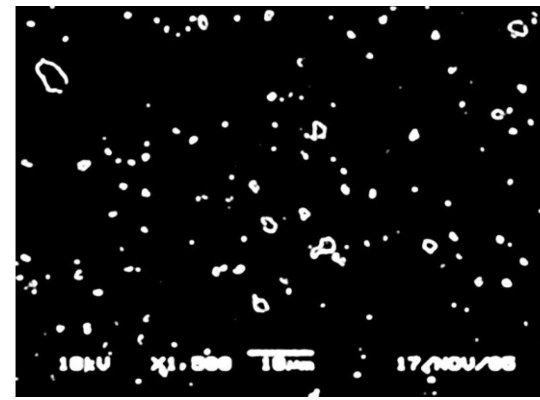


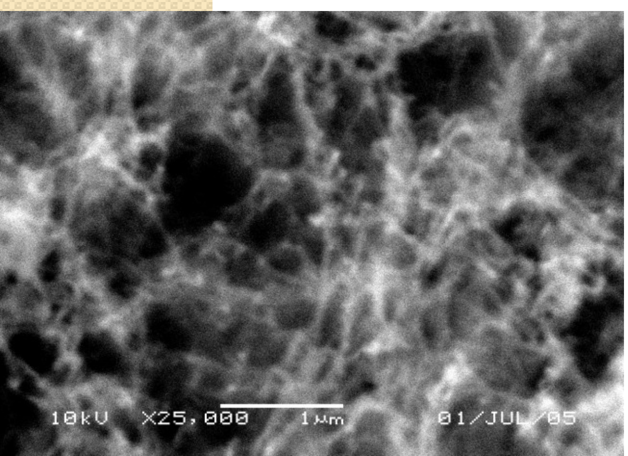






A.M. Khalenkov, N.G. Borisenko, V.N. Kondrashov, J. Limpouch, Yu.A. Merkuliev, V.G.Pimenov, Experience of microheterogeneous target fabrication to study energy transport in plasma near critical density. // Laser & Particle Beams, 2006, Vol. 24, pp. 283-290.

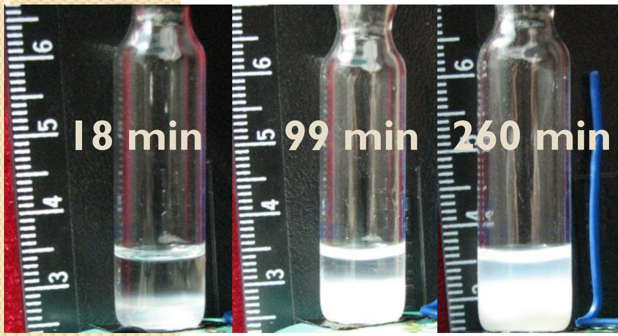




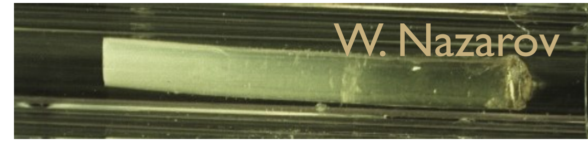
Soft (λ ~ 4.5 nm, E~286 eV) X-ray transmission image of TAC with density 4.5 mg/cc (left) and 10 mg/cc (right) with added 20% Cu by weight. High-Z particles agglomerates are clearly seen in the volume of 400 μm thickness. The net mesh is 0.5 mm.

I.A. Artyukov, N.G.Borisenko, Y.S.Kasyanov, A.M.Khalenkov, V.G.Pimenov, A.V.Vinogradov. Fabrication and characterization of low-density polymer laser targets both with or without high-Z dopants. // Proceedings of 29th European Conference on Laser Interaction with Matter (ECLIM), June, Madrid, 2006, pp. 147-151.

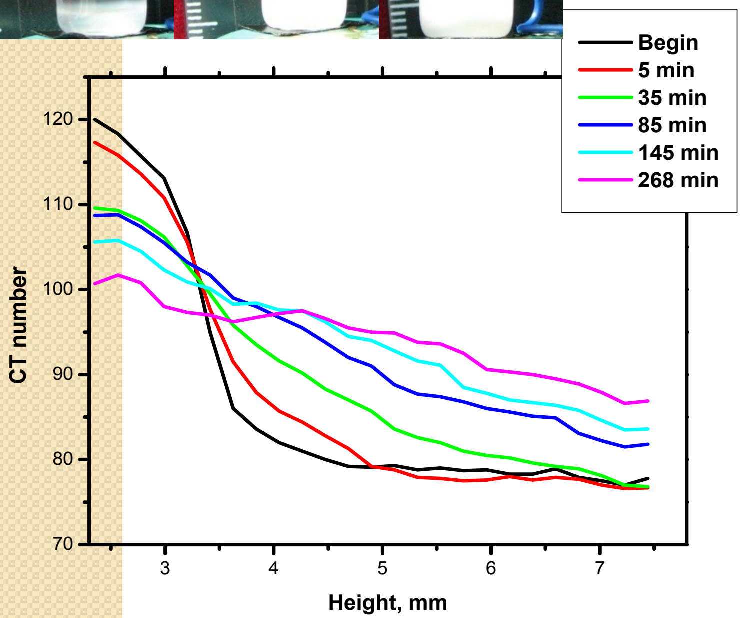
Density gradient characterization



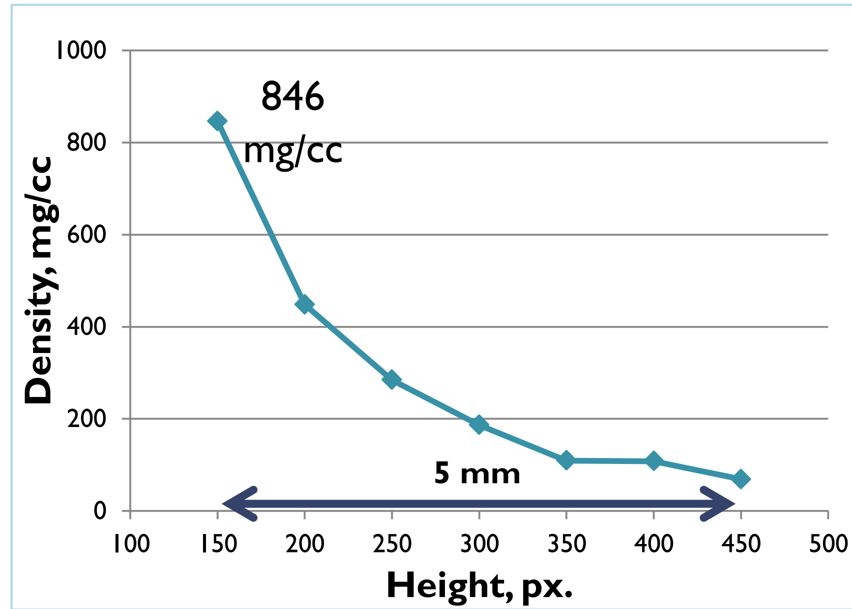
SiO_2 gel growing gradient
Yu.A. Merkuliev



DVB density-gradient aerogel



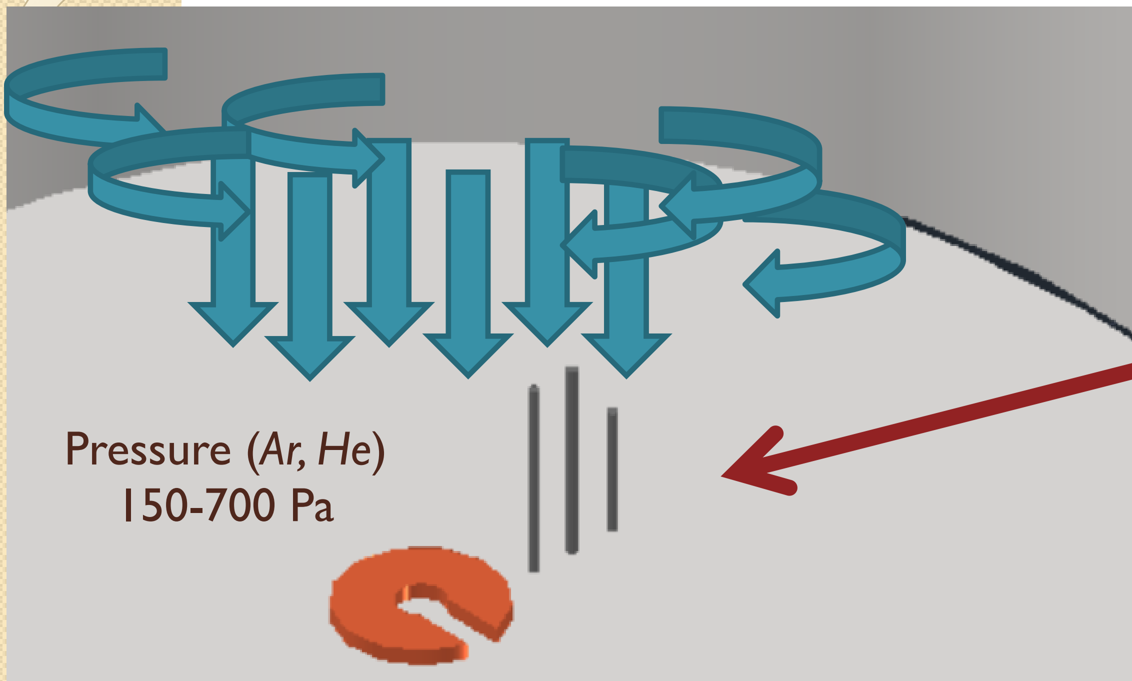
SiO_2 gel density in selected moments

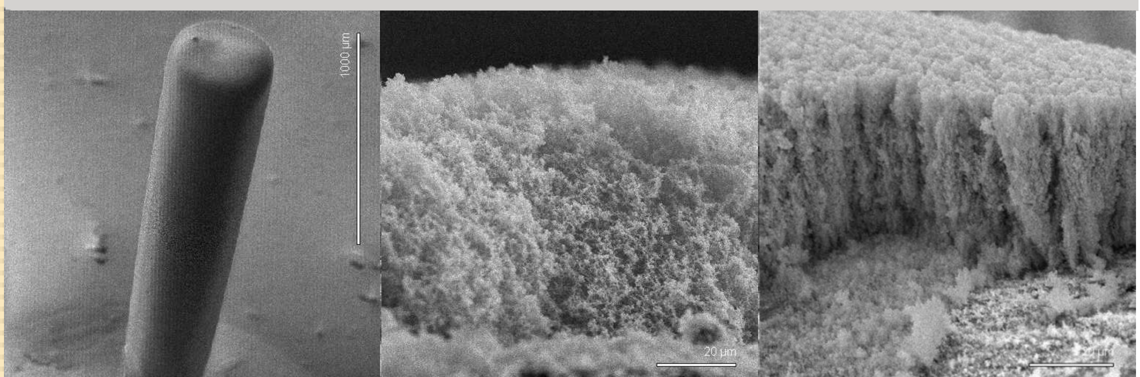


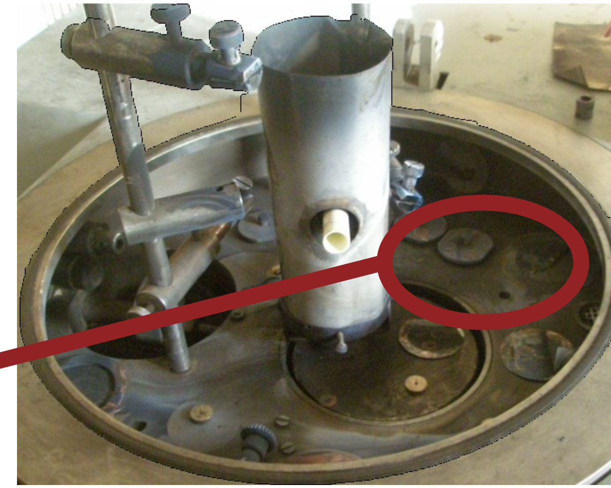
Density profile over height.
Maximum gradient – 400 mg/cc/mm
The goal: 1000 mg/cc/mm

X-ray tomography of growing silica gel with a density gradient. N. Borisenko et al. FS&T, Vol. 55, May 2009
X-Ray Tomography Method for Characterization of Aerogel Targets with Density Gradient. A. Orekhov et al. 4th Target Fabrication Workshop, Mainz, Germany, 19-23 August 2012

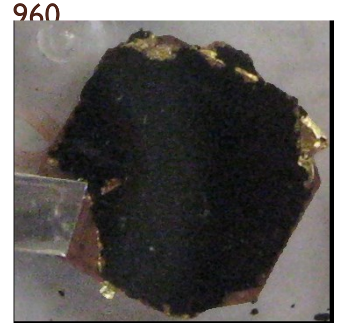
Nano-snow Layers Fabrication





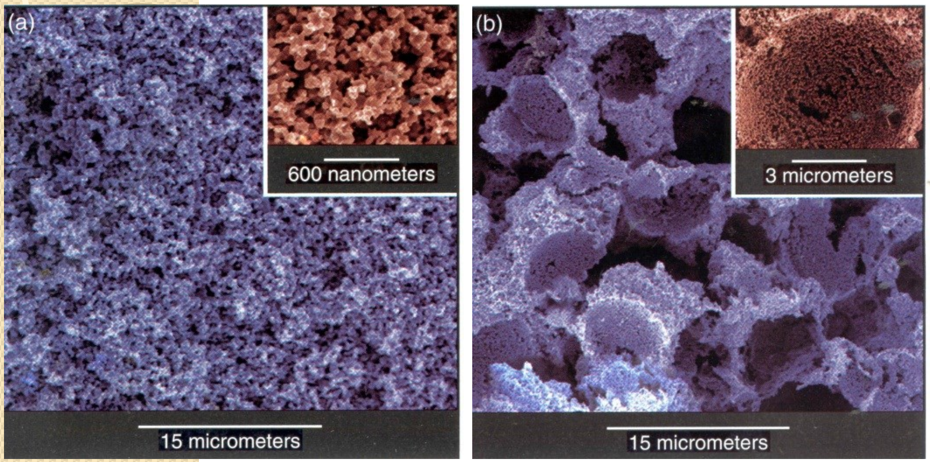


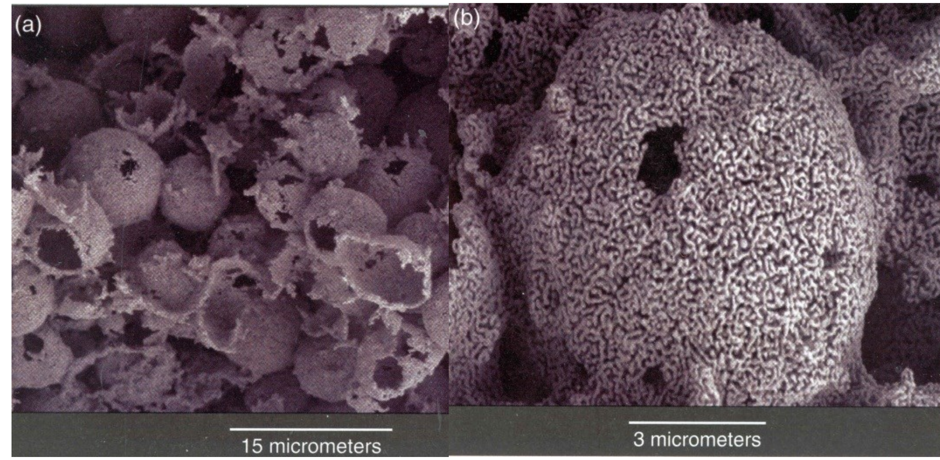
Gromov A.I., Borisenko L.A., Orekhov A. S. et al. (2014).
Metals produced as nano-snow layers for converters of laser light into X-ray for indirect targets and as intensive EUV sources. *Journal of Radioanalytical and Nuclear Chemistry*, *299*(2), 955-960.



Low density metals, structure monitoring

USA, Lawrence Livermore National Laboratory



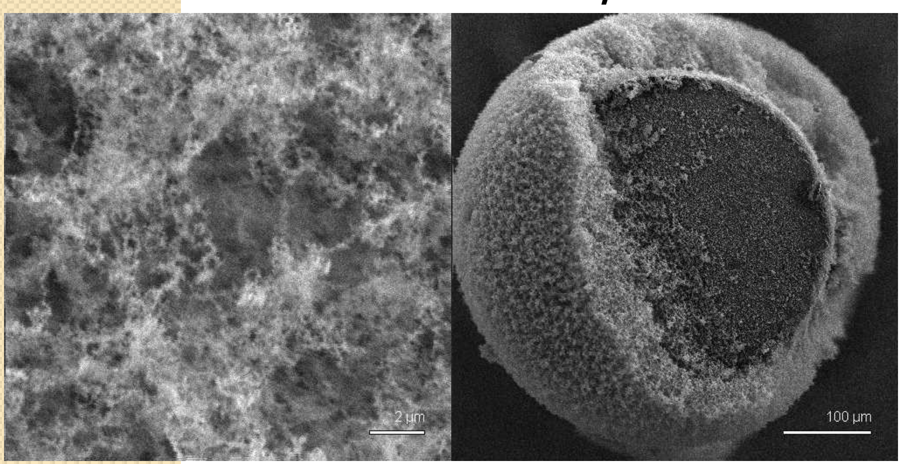


Low-density Cu nanoparticle layer

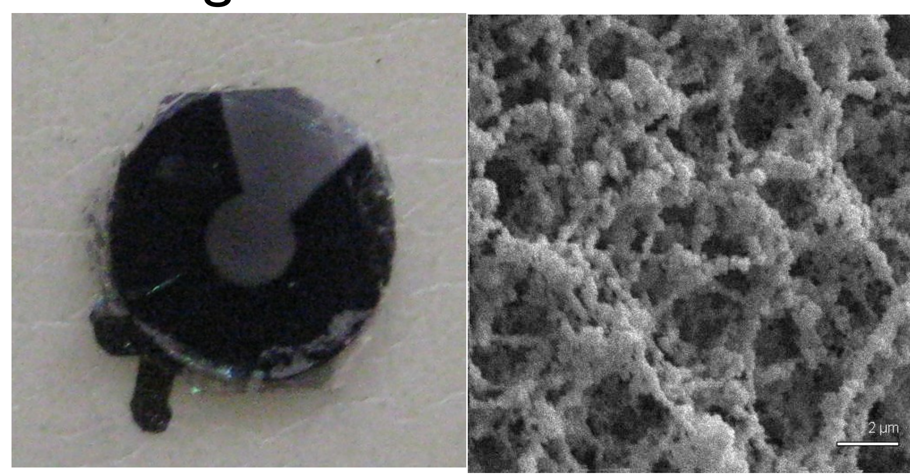
2,5 g/cc 0.1 g/cc

Low-density Au nanoparticle layer

LPI, Thermonuclear Targets Lab

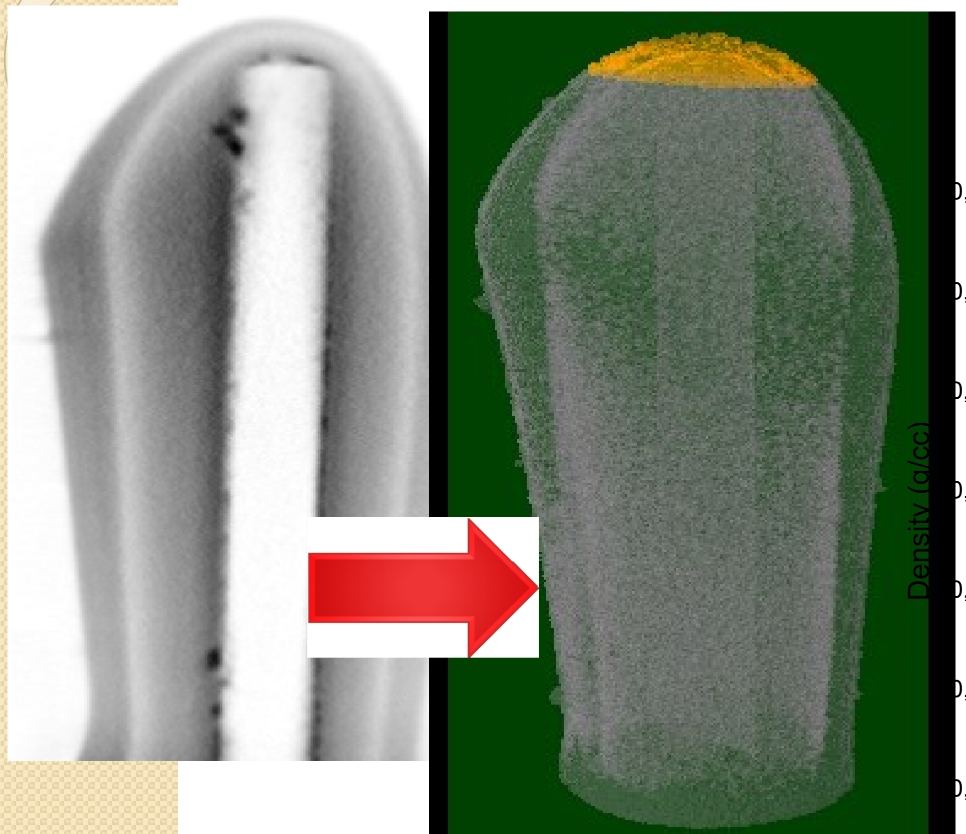


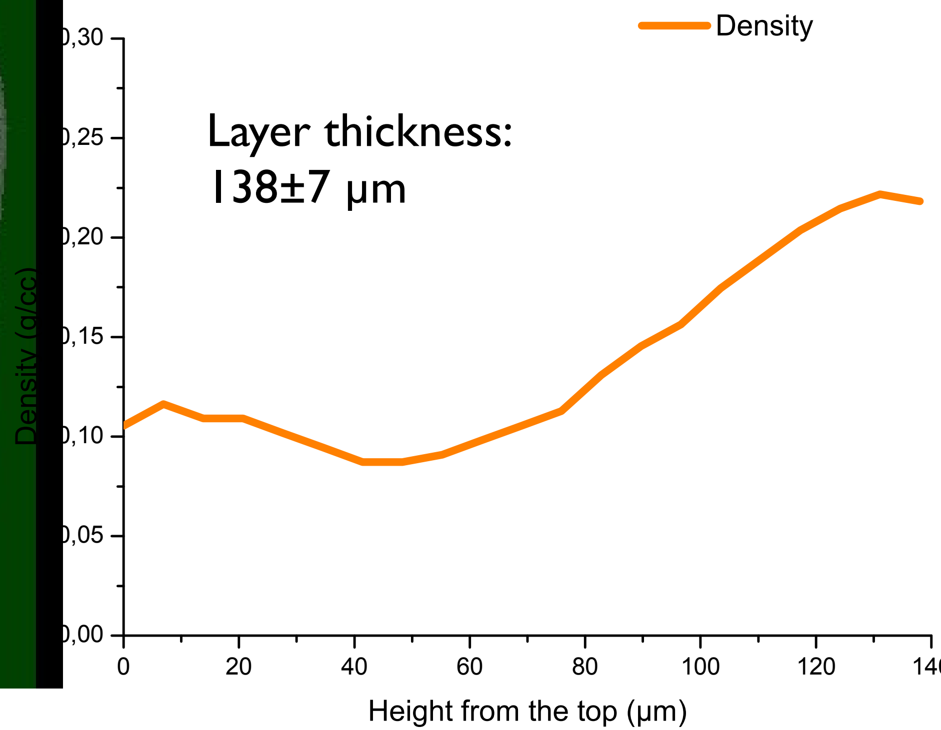
Au snow-like low density layer structure



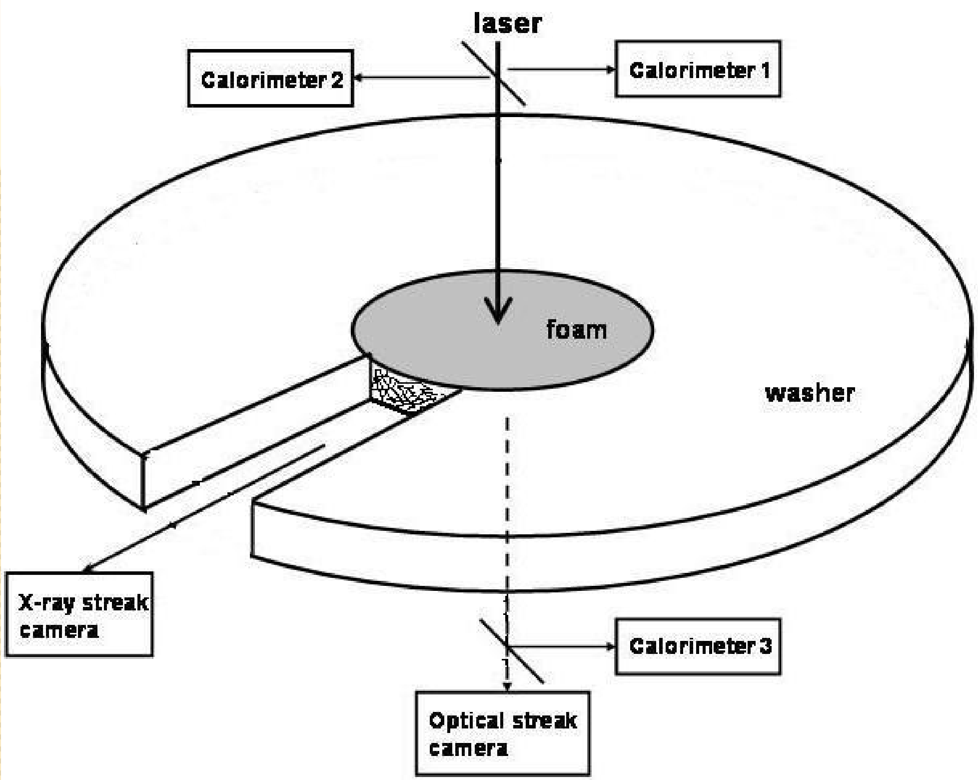
Bi low-density layer structure

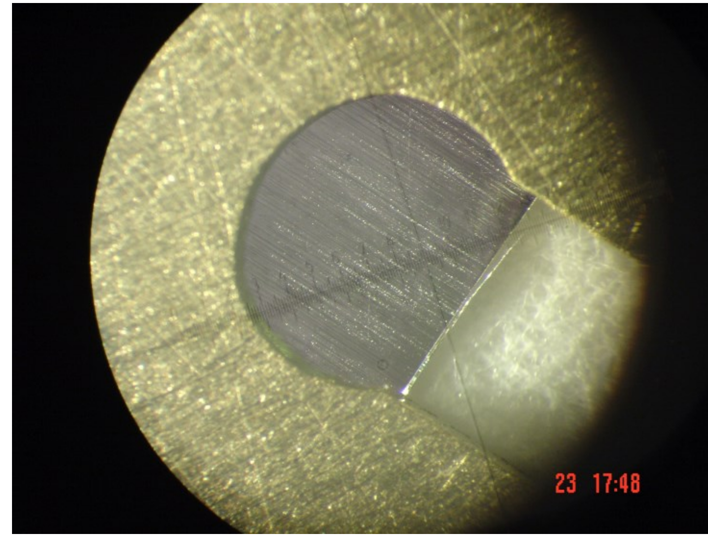
Gold Witness of Target Manufacturing

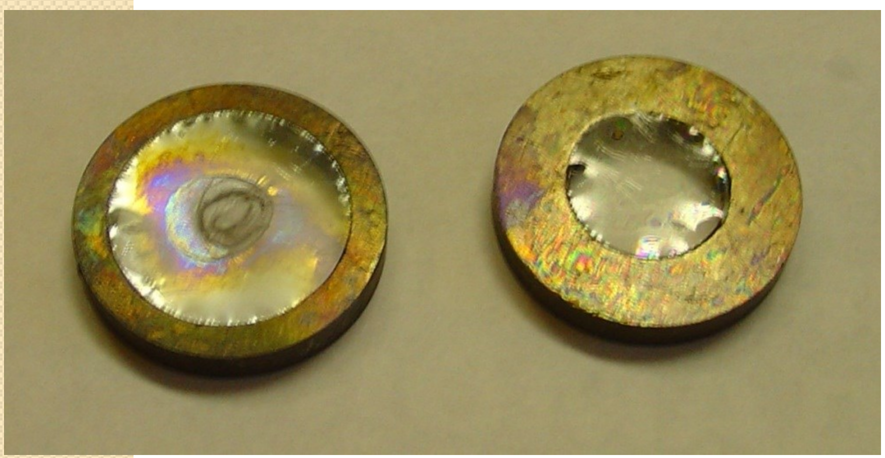


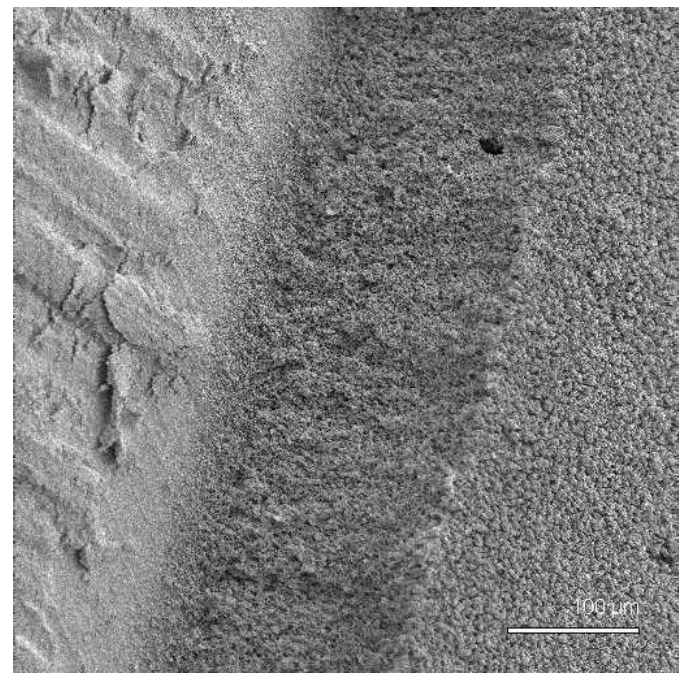


Target density and thickness are estimated by measurements of the witness

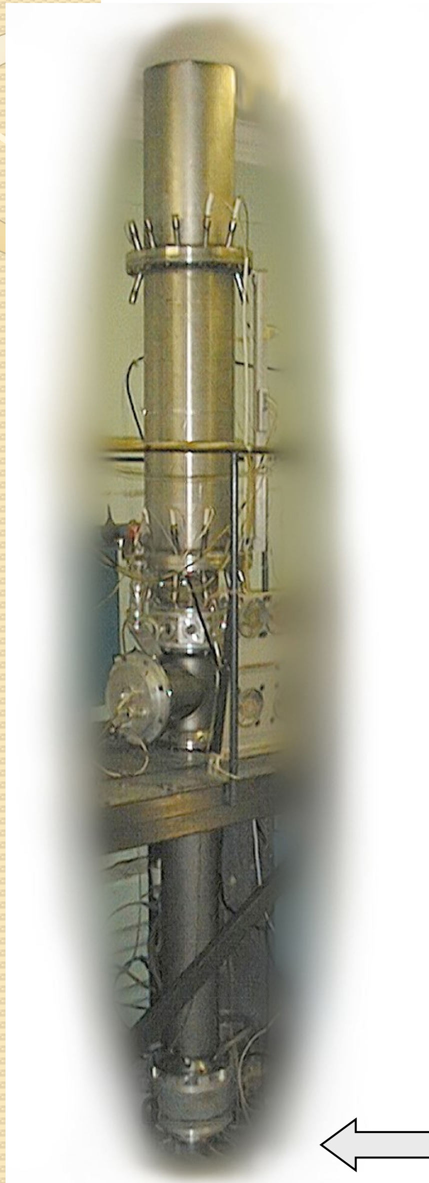

laser
Calorimeter 2
Calorimeter 1
foam
washer
X-ray streak camera
Calorimeter 3
Optical streak camera


23 17:48



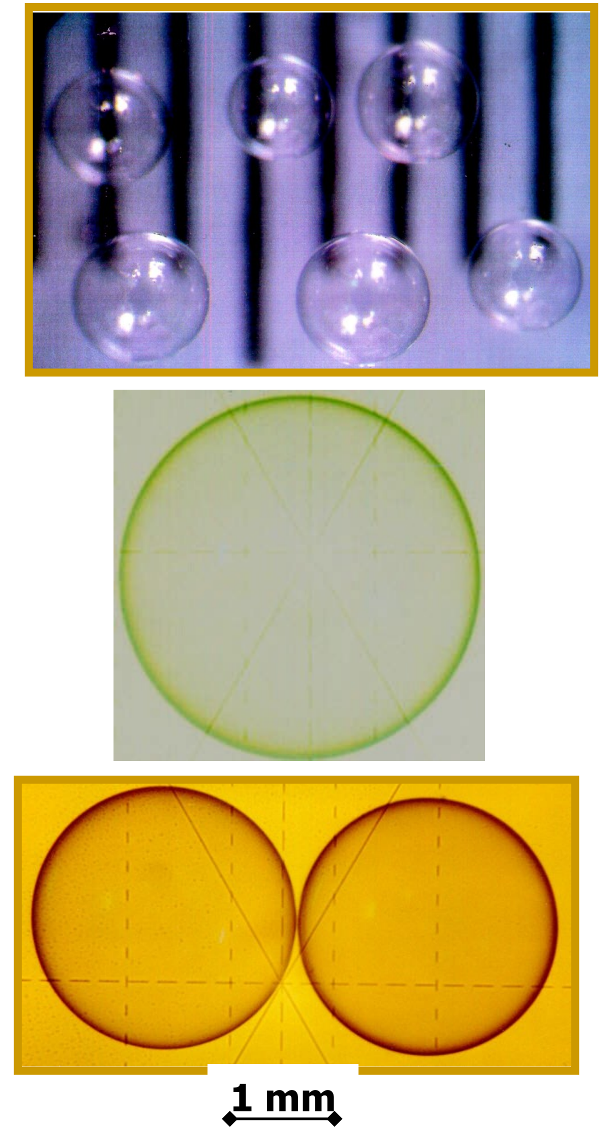

100 μm

FURNACES FOR POLYSTYRENE MICROSHELLS PRODUCTION



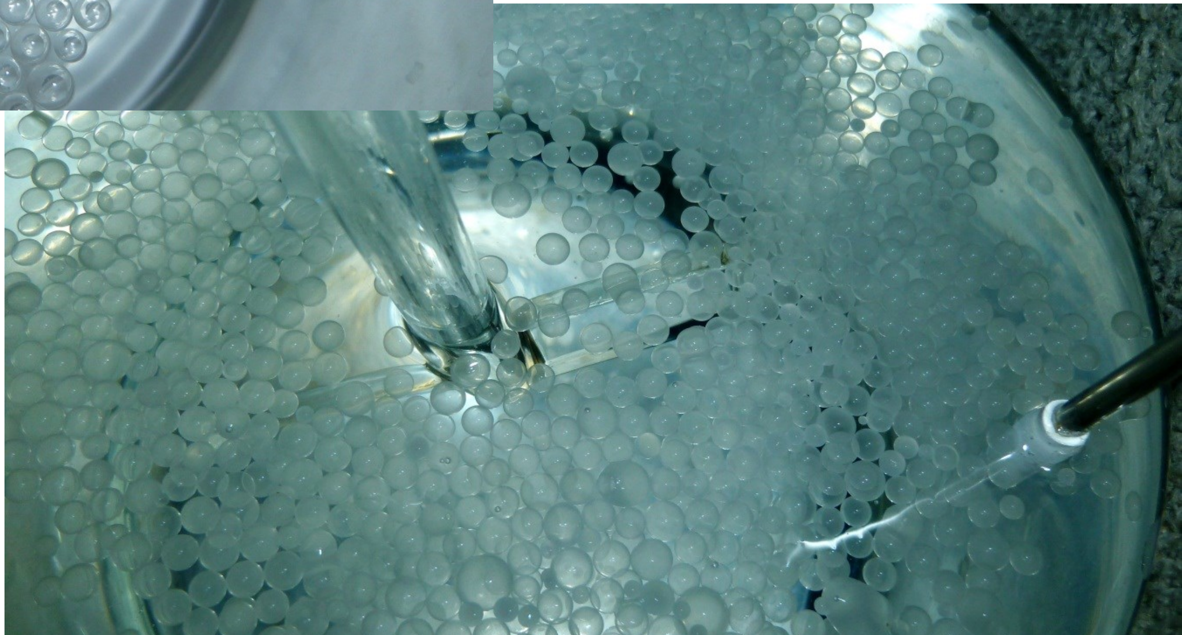
Ballistic furnace

Vertical furnace

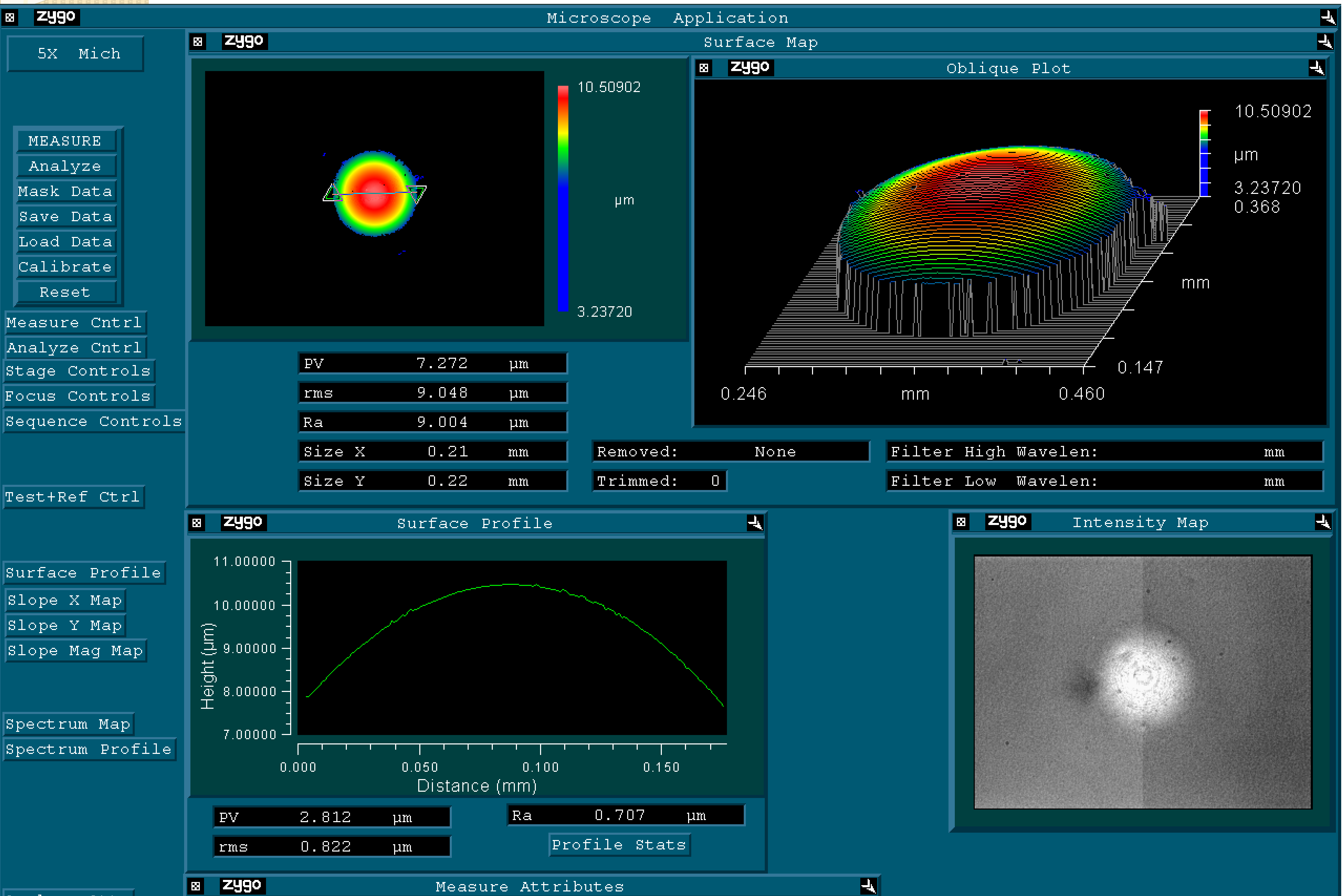


Polystyrene microshells

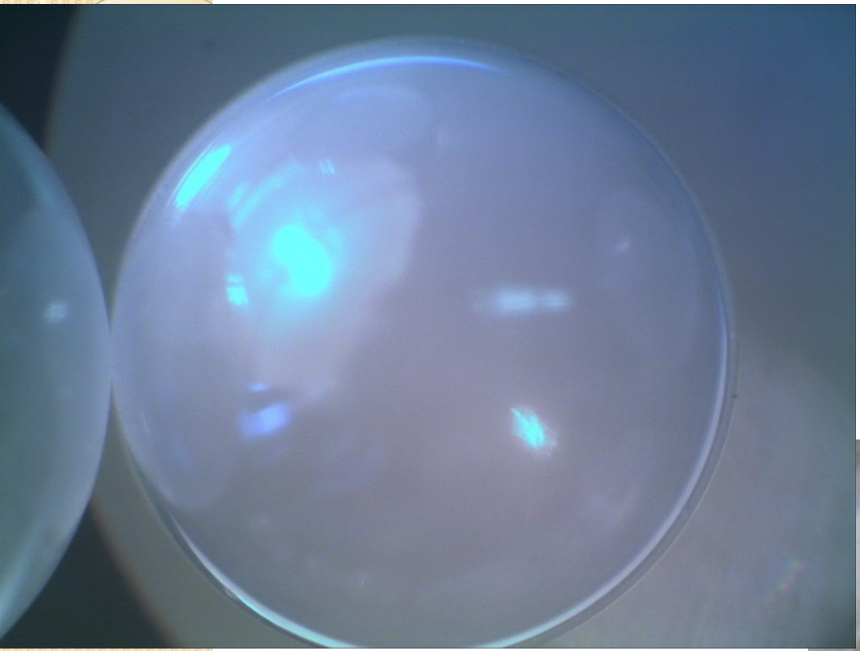
Return to thermonuclear targets: PS and PAMS spheres production study

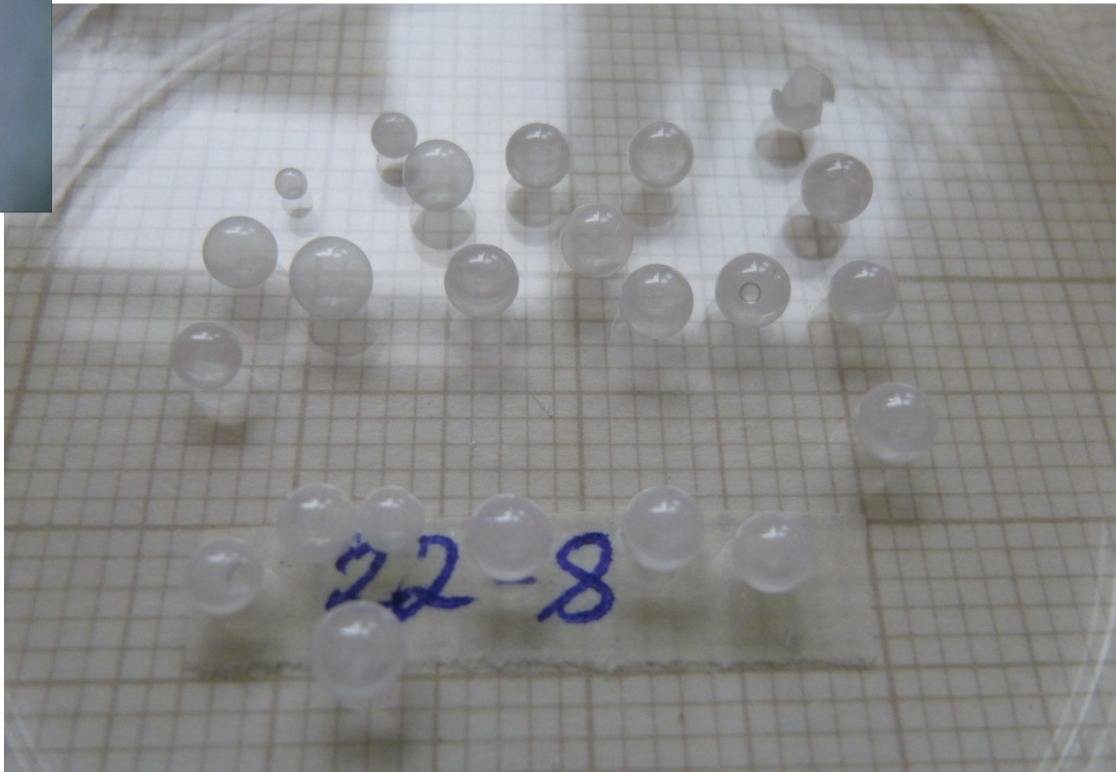


Profilometer Zygo is suitable for characterization and for microencapsulation technology studies



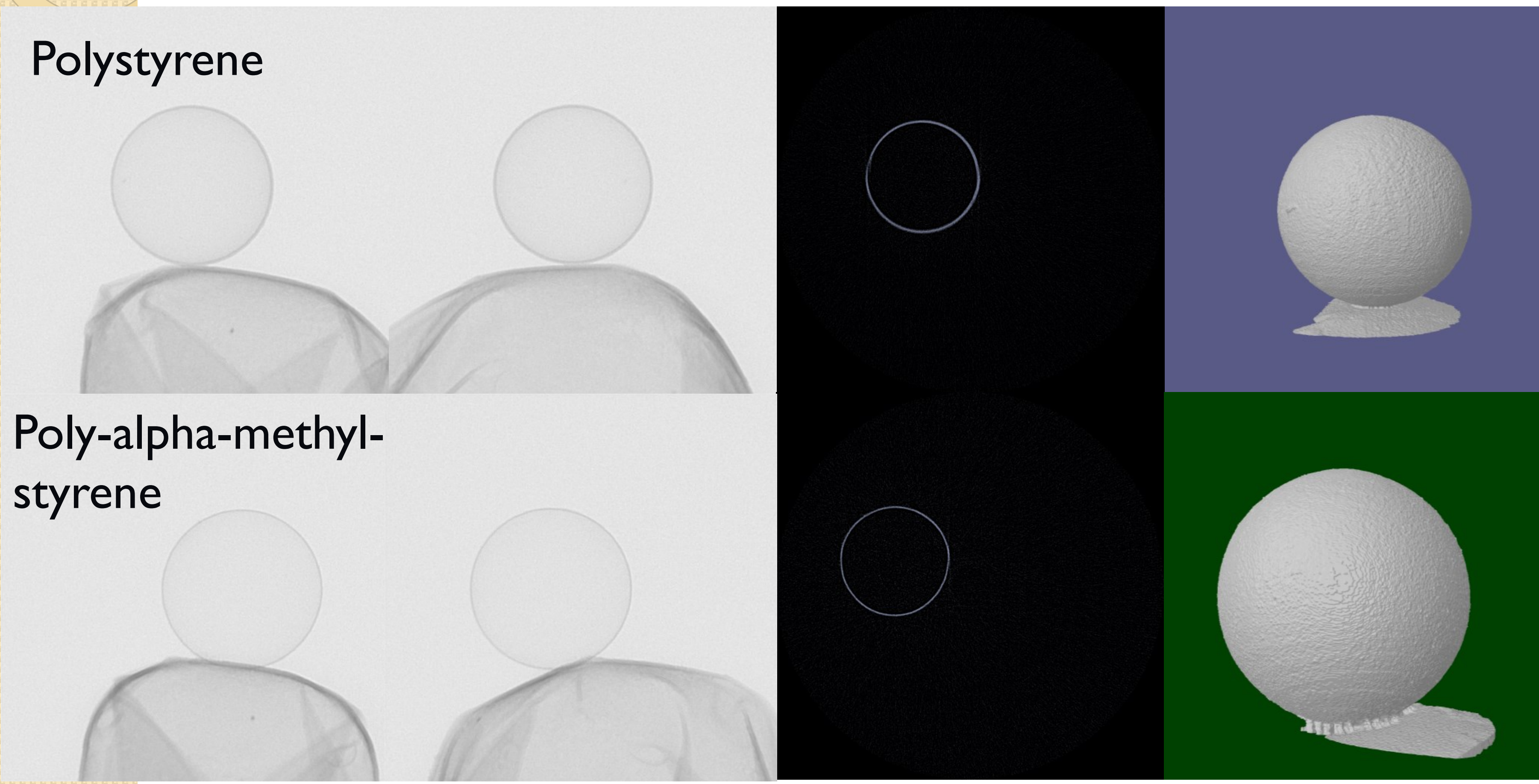
PAMS 2060-micron sphere and research samples with no inner water for profilometer study (Pastukhov, Davankov)



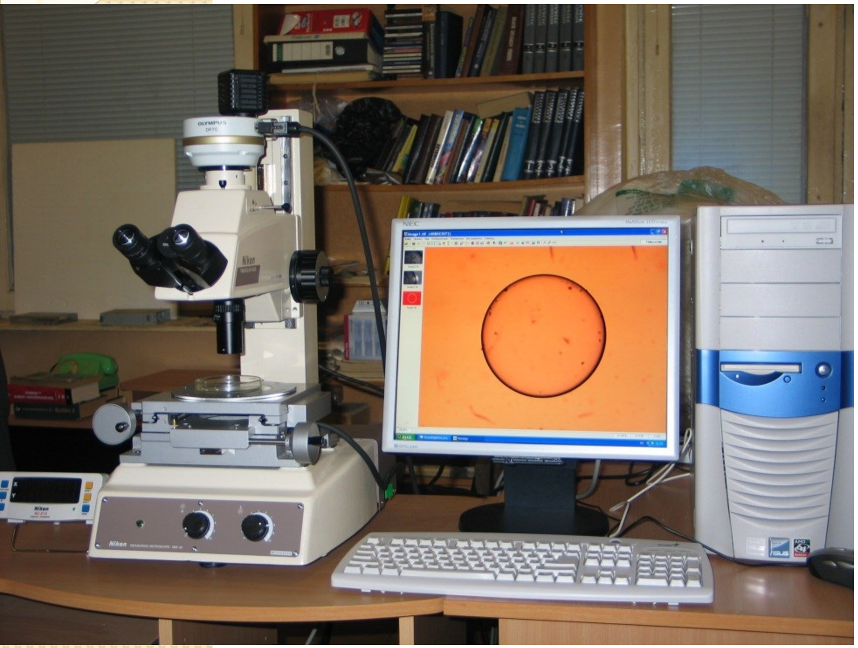


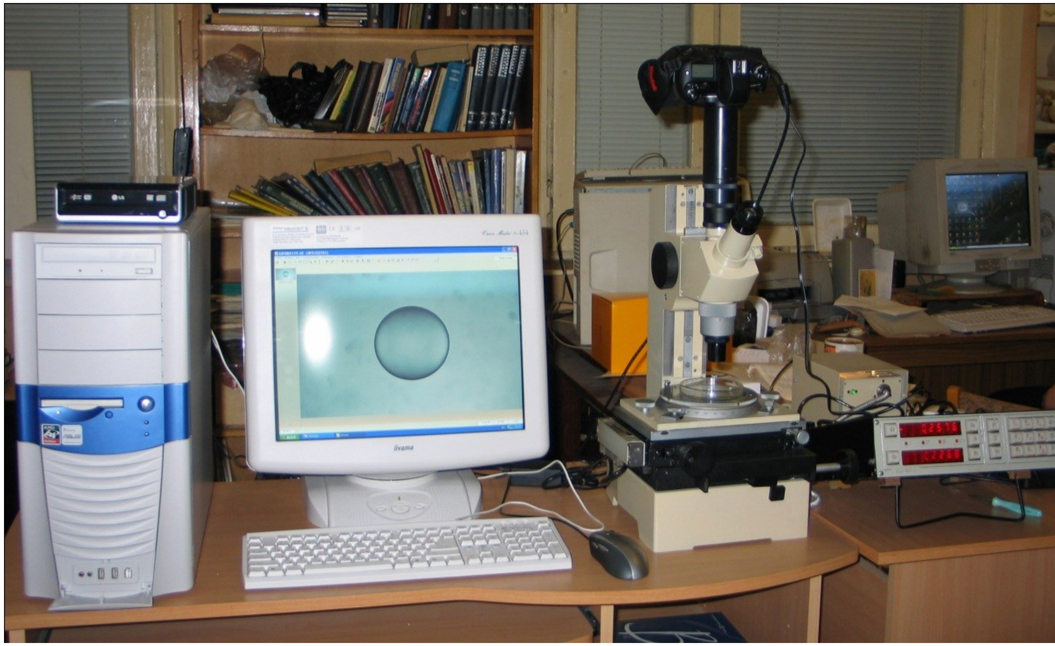
Polymer microspheres 1.2-1.3 μm

Sphericity test with SkyScan 1174 (Orekhov)



Optical and x-ray shell characterization





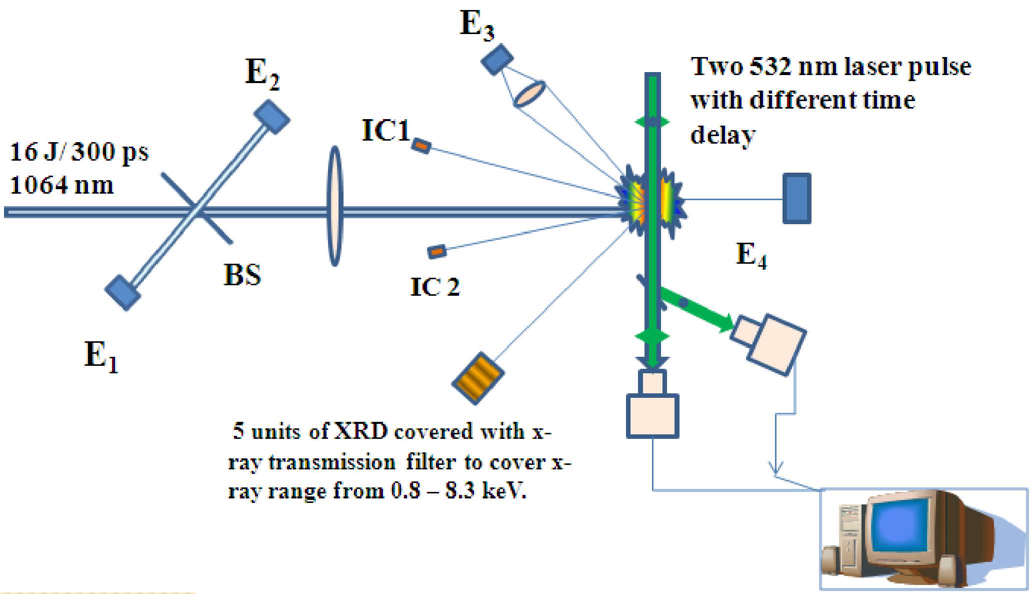
Two automatic optical systems with high resolution CCD-camera and original software for shell characterization. Made in LPI and delivered to different Russian Institutes. Software had been written using ray-tracing method in 2001. Now it also includes wave-let analysis of 100 – 200 images for single or double-layer shell.

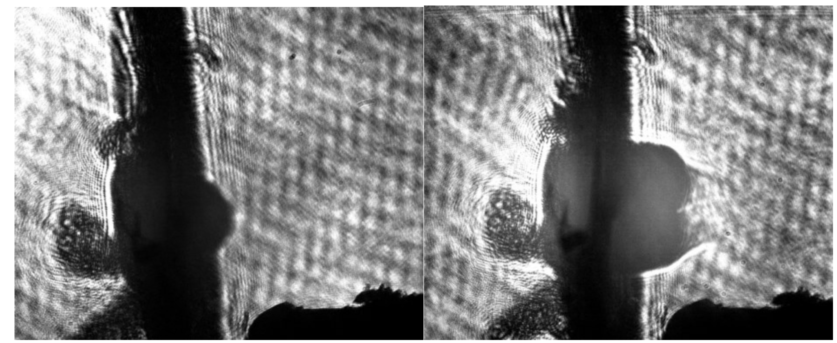
Nikitenko, Tolokonnikov:

Koresheva E. R., Nikitenko A.I et al. Possible approaches to fast quality control of IFE targets. Nucl. Fusion **46** (2006)
A.I.Nikitenko MP15 Report on Target Fabrication Meeting 1-5 October, 2006, San Diego, CA, USA

Experiments in BARC (Mumbai, India, ≥2009)

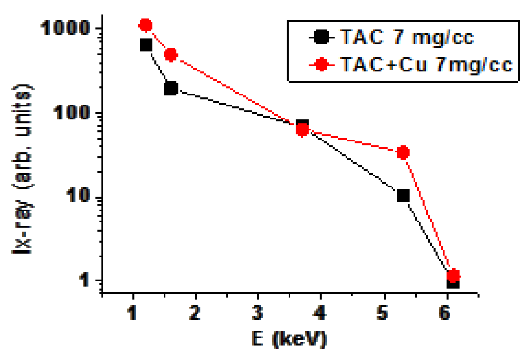
Team: S. Chaurasia, P. Leshma, D.S. Munda, L.J.Dhareshwar, N. Borisenko, A. Orekhov, A. Gromov, Yu. Merkuliev *et al.*



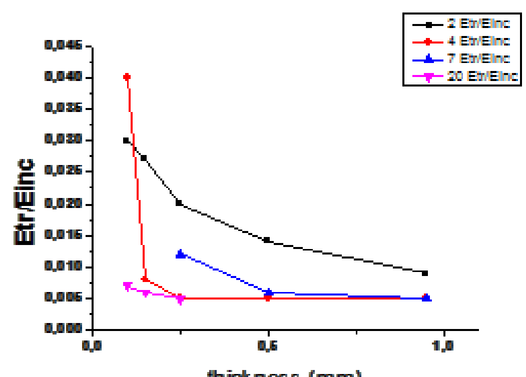


Shadow images of plasma expansion

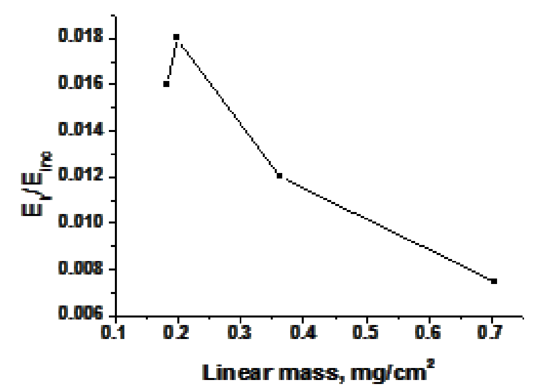
~3 ns ~6 ns



X-rays spectra in CTA plasmas with Cu nanoparticles

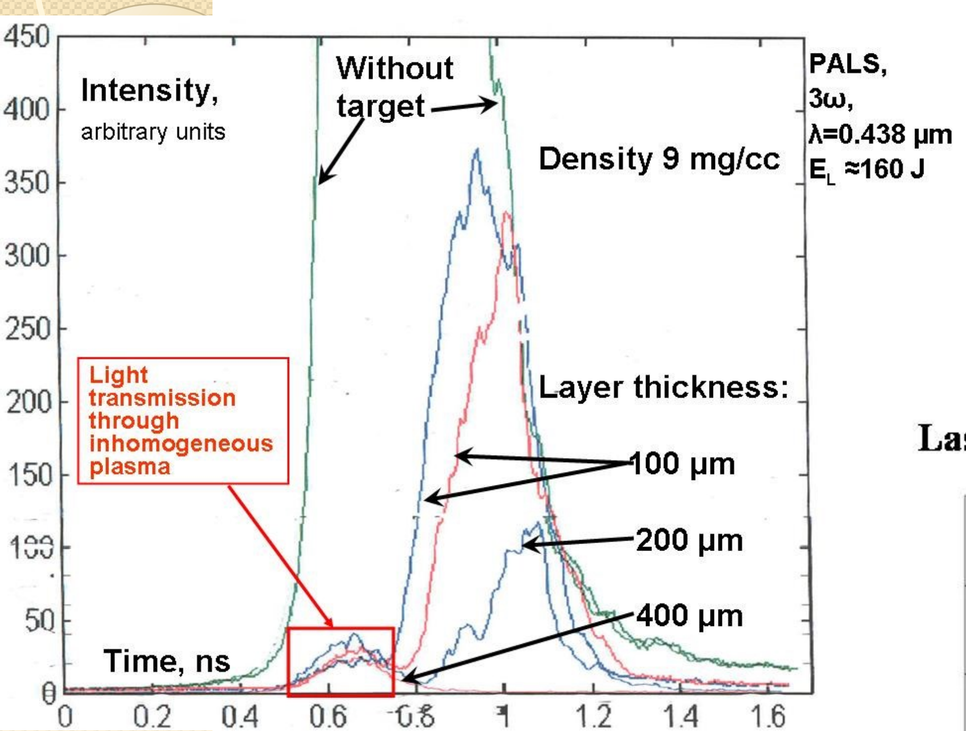


Transmitted light fraction over thickness of the target for different initial densities



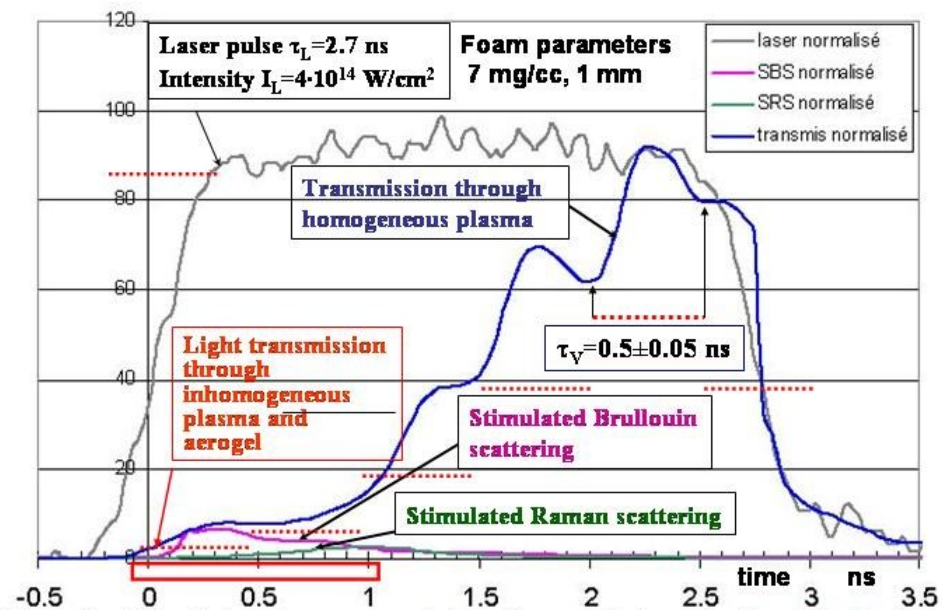
Transmitted light fraction over linear density for thick (0.9-1mm) targets

PALS & LIL comparison (1 of 2)



J.Limpouch, N.G.Borisenko et al., Laser Absorption and Energy Transfer in Foams of Various Pore Structures and Chemical Compositions. // Journal de Physique IV (France), June 2006, Vol. 133, pp. 457-459

Laser radiation transmission through undercritical aerogel.



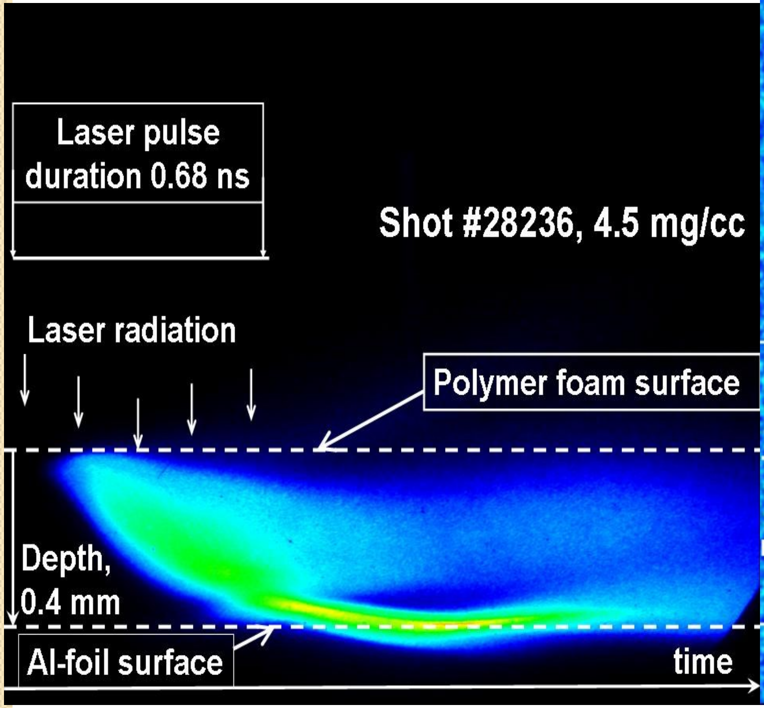
Normalized signals from laser, transmission of laser radiation, stimulated Bruillouin scattering, stimulated Raman scattering. (LIL 2007 experiment)

L. Viedeau, E. Alozy, I. Bailly et al., Owerview of on-going LIL experiments. // Plasma Phys. Control. Fusion. 2008, V. 50, No 12, Art.No 124017

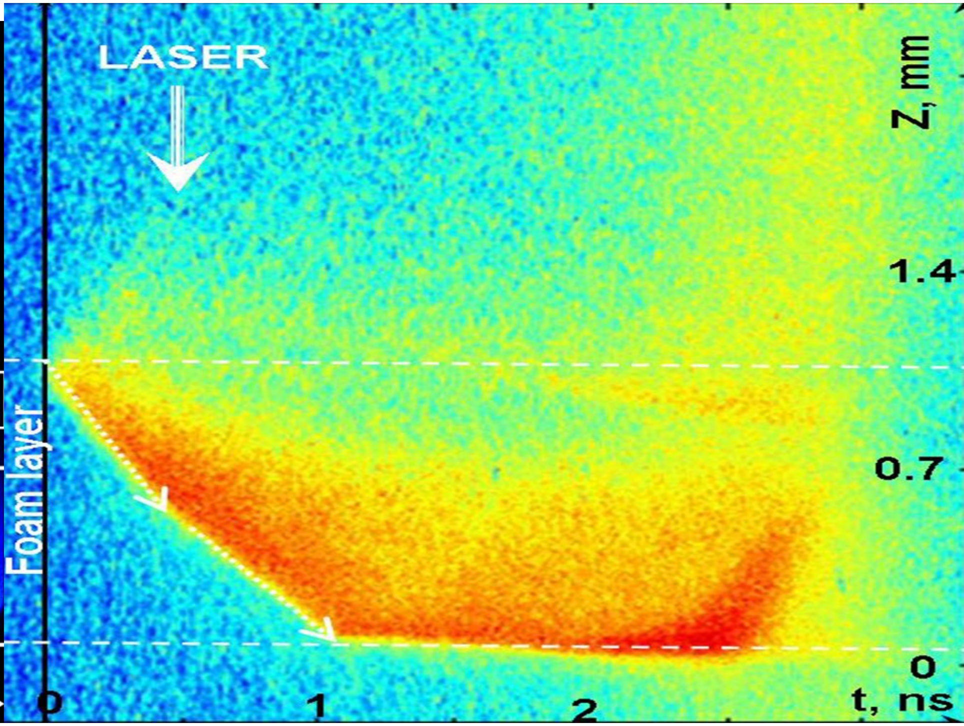
PALS & LIL comparison (2of2)

- *Supersonic waves formed*

Target by LPI-IOC 2005
TAC, 4.5 mg/cc, 400 μm +Al foil, 5 μm
frame duration - 2 ns

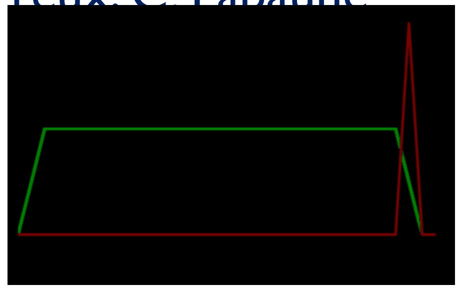


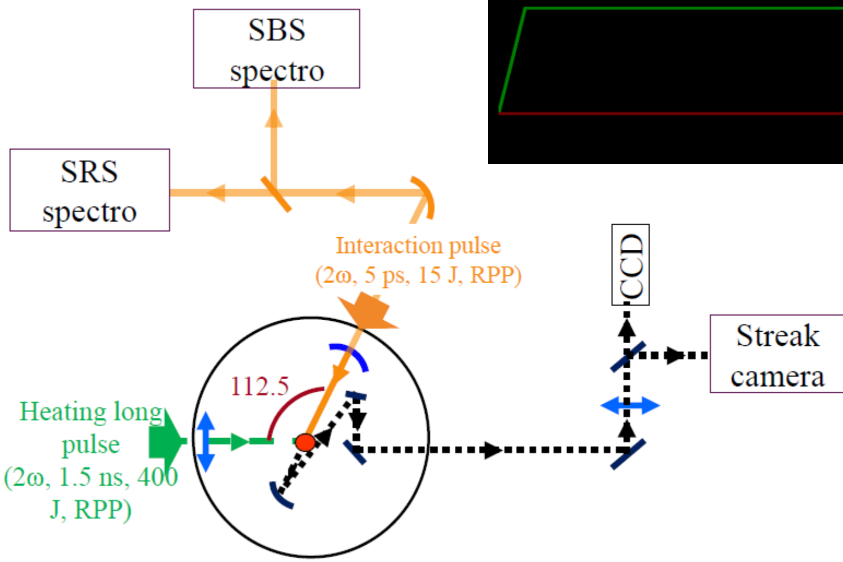
Target by W. Nazarov, Univ. of St Andrews
TMPTA, 10 mg/cc, 1000 μm +Cu foil, 30 μm
2007

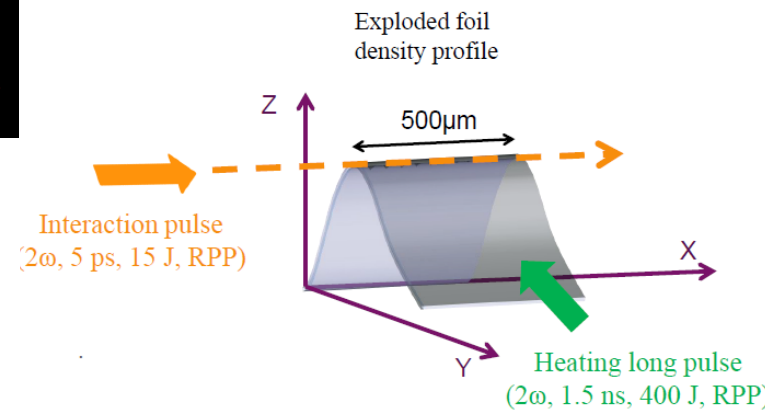


Experiments on LULI2000 (France, 2012)

Principle investigators: S. Depierreux, C. Labaune

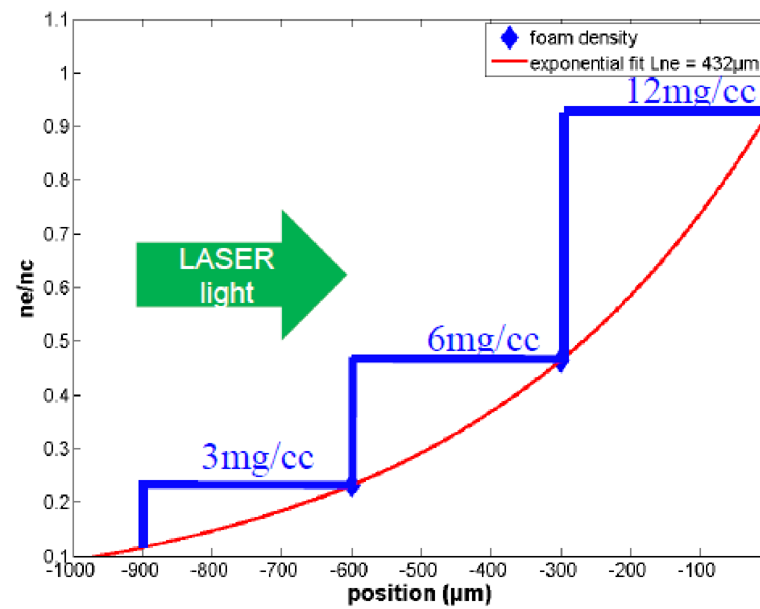






2 laser beams
Heating: 2ω, 1.5ns, 400 J
Interact: 2ω, 5ps, 15J

Wide range of densities:
$0.1n_c \sim 1n_c$

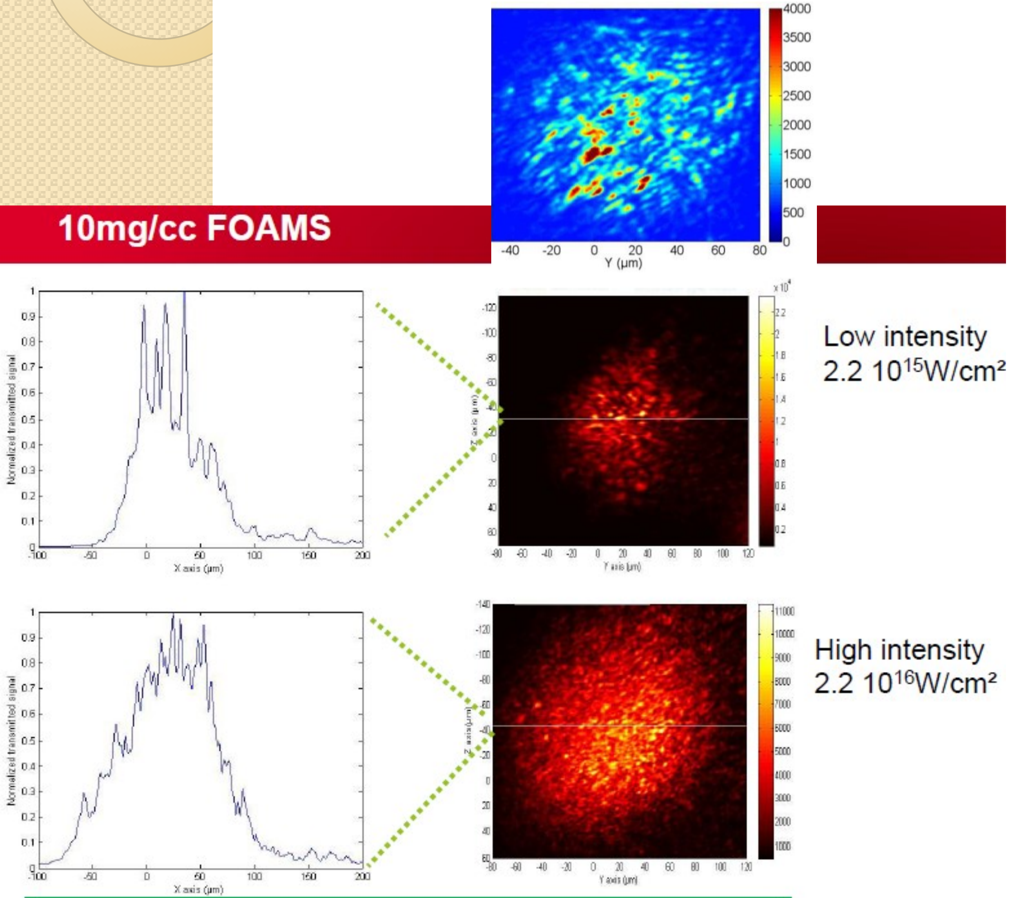


C. Goyon, *et al.* ECLIM 2012, Warsaw, Poland, 09 September 2012.

Experiments on LULI2000 (France, 2012)

Principle investigator: S. Depierreux, C. Labaune

Self-focusing with increasing intensity



⇒ Higher intensity shot evidences reduction of contrast and smoothing by the plasma

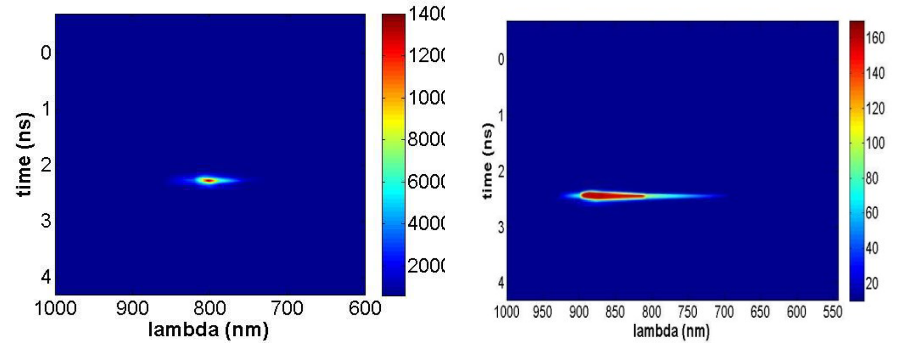
CEA | Clément GOYON

SRS spectra broadening

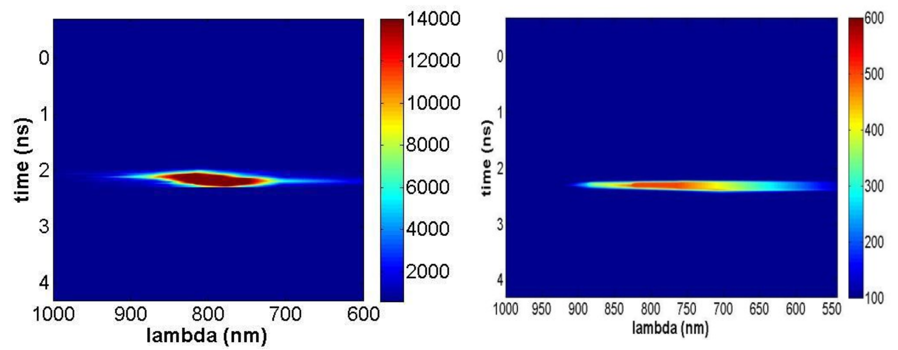
Mylar 2.5 µm

CTA, 3 mg/cc 500 µm

$2.2\ 10^{15}$ W/cm²



$2.2\ 10^{16}$ W/cm²



C. Goyon, *et al.* ECLIM 2012, Warsaw, Poland, 09 September 2012.

Experimental activities

Facility	λ[nm]	τ, E	Selected results on aerogels
MISHEN (TRINITI, Russia), many series	1064	2.5 ns, 100J	Hydro and thermal waves velocities, plasma jets and dynamics
Kanal-2 (LPI, Russia), many series	1064	2.5 ns, 50 J	Nonlinear scattering of broad-band laser light, energy balance
NEODYM (TsNIIMash, Russia), PI I.S. Belyaev	1064	10 ps, 15 J	Dependency of neutron yield on $(CD_2)_n$ density, nuclear reactions with borine
BARC (India), PI S. Chaurasia, N. Borisenko	1064	0.7 ns, 16 J	X-ray emission from nano-snow and aerogels, energy balance, dynamics
PALS (Prague, Czech), PI J. Limpouch, O. Rosmej	438	0.37 ns, 200 J	Opacity and radiance of aerogel plasma, indirect heating.
PHELIX (GSI, Germany), PI O. Rosmej	532	2 ns, 160 J	Heavy ion stopping power in CTA plasma, x-ray heating of aerogel
LULI-2000 (Ecole Polytechnique, France), PI S. Depierreux, C. Labaune	532	1.5 ns, 500 J & 1 ps, 70 J; 2beam 1.5 ns, 1KJ	SBS, SRS and non-linear effects in plasma at laser intensities up to $3 \cdot 10^{16}$ W/cm^2, shock ignition related topics. Multiple plasmas interaction.
LIL (Bordeaux, France)	355	2.7 ns, 10 kJ	Laser radiation smoothing, supersonic waves, energy balance, time resolved SRS, SBS
GEKKO-XII (Osaka University, Japan), PI P. Nicolai, Sh.Fujioka	532	1.5 ns, 2000 J	Shock waves, instability seeded and relaxed Magnetized plasma

Plasma induced smoothing 2007

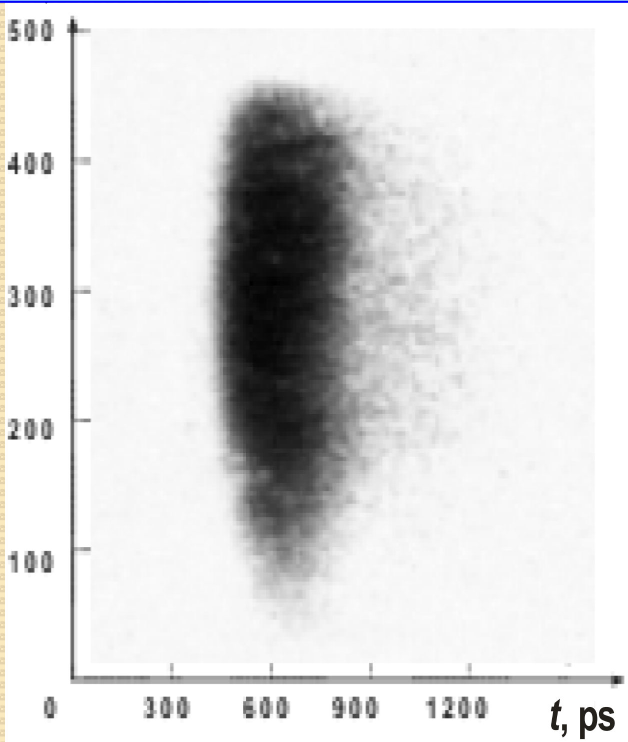
Purpose: ***reducing of laser induced shock nonuniformities by temporal smoothing of laser spot irregularities . Method concludes in laser coherence reduction when passing through undercritical plasma layer. The dynamical plasma phase plate method is found to have great efficiency:***

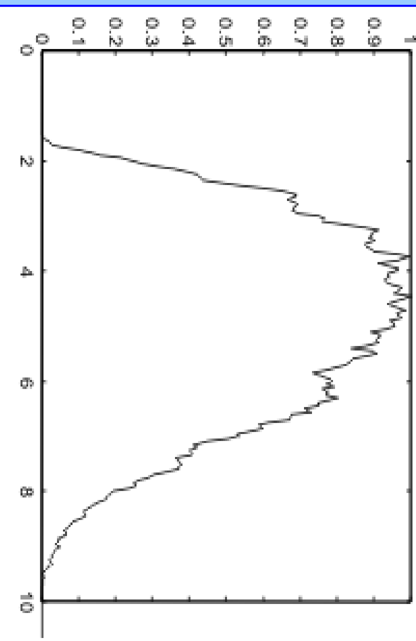
- ***Energy transition >80%***
- ***Speckles redistribution 0.4 ps***
- ***Nonuniformity <3%***
- ***Smoothing duration >300 ps***

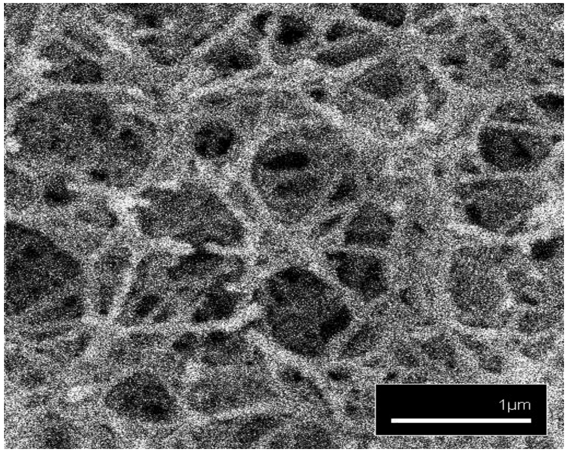
DPPP smoothed beam

Streak-camera image

Cross-section intensity integral (over the pulse duration)







Undercritical foams advantages:

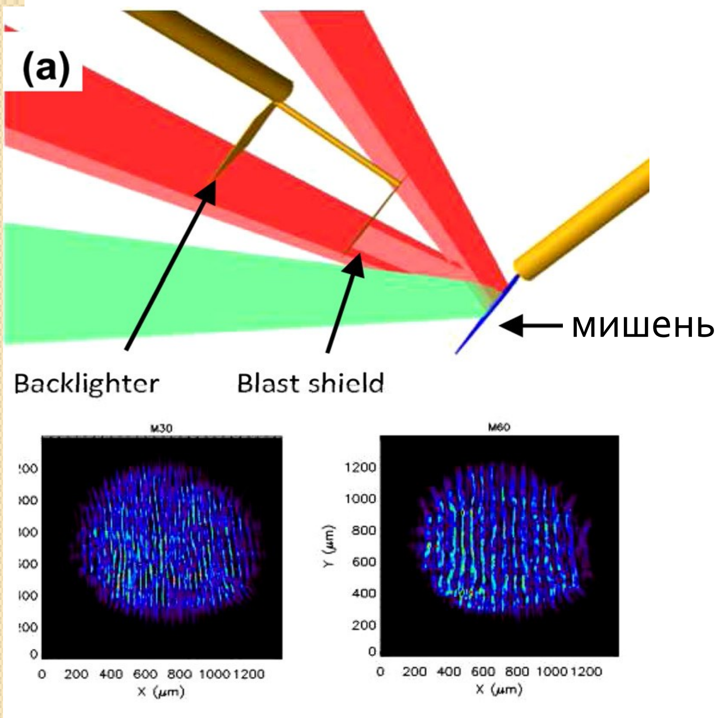
Smoothing starts with front of pulse;

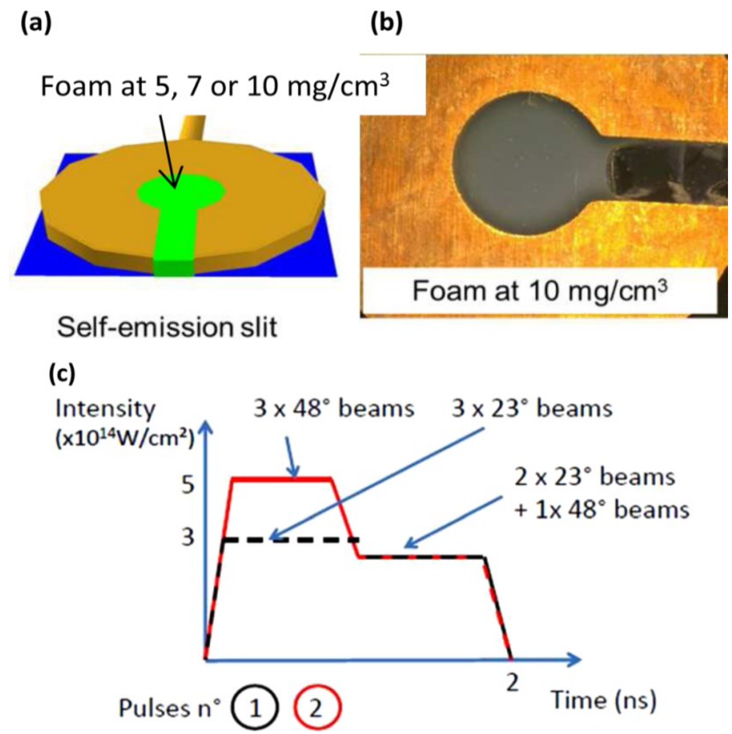
- ***Smoothing duration increased to ≈1 ns;***
- ***Efficiency increased of scales smoothing towards several hundreds microns.***

Experiments started with foams:

- ***Density 1-2mg/cm^3 & thickness 100-200 µm***
- ***Transition is achieved ≈60% and >80% is forecasted***

OMEGA, LLE, Rochester Univ. 2014





Foam mitigates key obstacle in quest for laser fusion

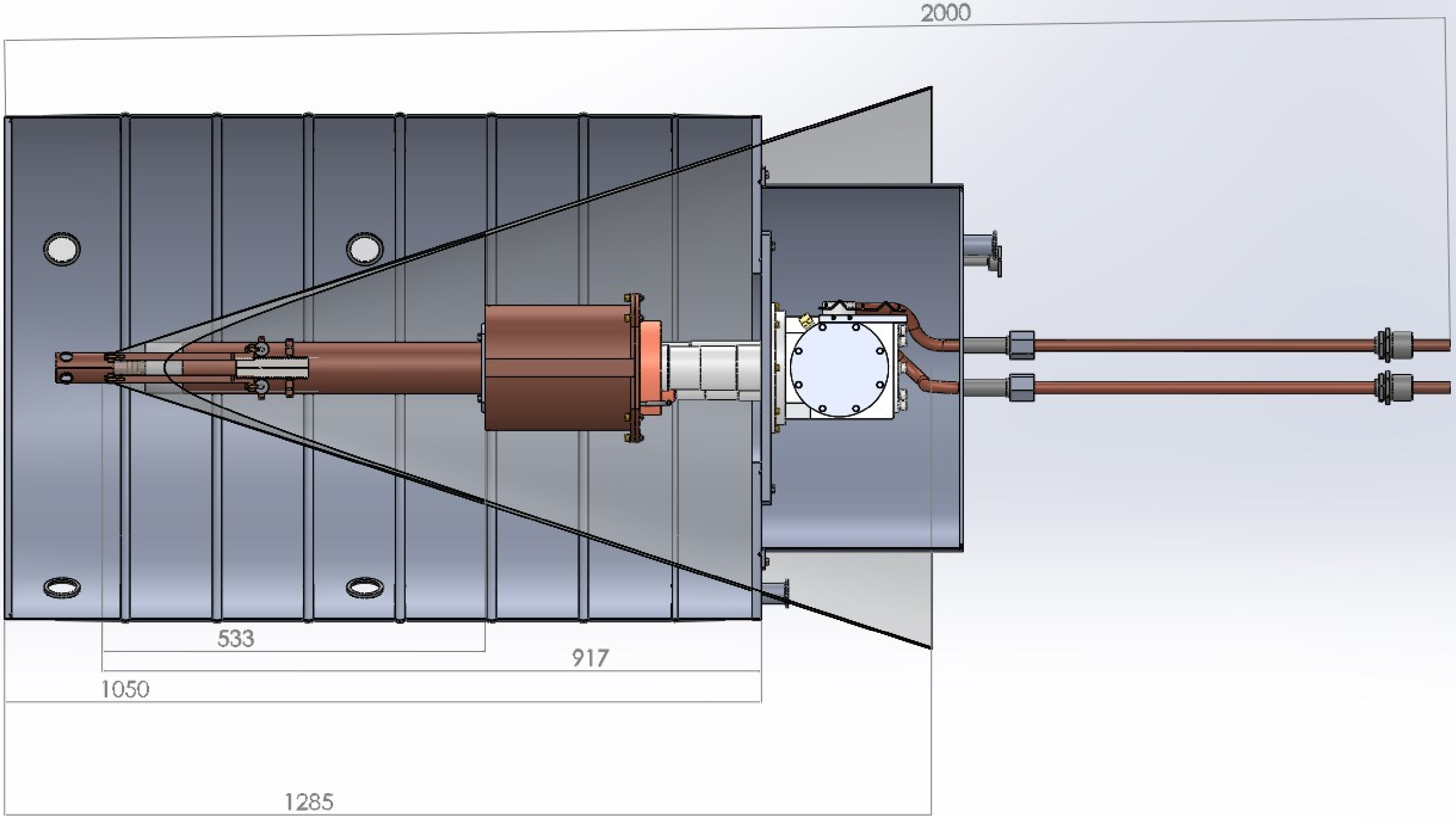
Andrew Grant
14 April 2016

A thin layer of wispy foam reduces the impact of Rayleigh–Taylor instabilities and thus enables more even implosions.
PHYSICS UPDATE

Now an international team of physicists using the OMEGA laser at the University of Rochester in New York has reduced Rayleigh–Taylor instabilities with the help of extremely low-density foam. The researchers spread the foam over a thin sheet of foil (see image below), which served as the target in place of a fuel capsule. Once struck by six 500-joule beams, the foam vaporized instantaneously into a plasma, which smoothed out imperfections in the laser beams before the light reached the foil. The researchers found that a 500 μm layer of 7 mg/cm^3 foam reduced the imprint of laser imperfections by a factor of two. The next step is to envelop a round capsule with the foam in an attempt to achieve perfectly spherical compression.

B. Delorme et al., Physics of Plasmas

Development of the indirect-drive cryogenic spherical target input to the center of 3 MJ-class laser driver (LPI)



Concluding remarks:

The full-spectrum target activity of the P.N.Lebedev Physical institute is now facing all the challenges of the contemporary phase of ICF/IFE research.

Flat structured targets are provided for non-thermonuclear shots. To the beginning of NIF operation we could propose targets of plastic aerogels and nanoparticle layers for many laser and beam experiments.

After NIF has started our targets worked for laser experiments on ionization wave, instability mitigation, particle and e-m waves generation, SRS and SBS studies, energy transfer and transport in underdense targets (both in Russia and in the course of International projects). The shock ignition questions, indirect scheme and particle beam interaction with laser plasma were actively pursued. The cryotarget group is led by prof. E.R.Koresheva to realize unsuspended cryotarget formation and its rep-rate delivery to the laser focus.

Now on certain stage of NIF operation a scientific breakeven was hopefully reached. Russian program for 2MJ laser of new generation has started [*G.A.Vergunova et al.* on IFSA 2013]. A new request for large and complex target development appeared for expected ambitious European projects. Extremes of pico- and femto-second lasers are also on the schedule. We work for these dominating tendencies to be ready with spherical and layered target as well as density gradient in them.

- Thank you for your attention!

The work is partly supported by Indian-Russian DST-RFBR joint project

RFBR 15-52-45116