Perspective targets for high energy density physics investigation

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EMMI Workshop on Plasma Physics, May 2, 2011, Darmstadt

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Outlook

1. Motivations

2. Investigation of shock compression of SiO_2 – aerogel using synchrotron irradiation

3. Investigation of shock compression of Fullerite C_{60}, Fullerite C_{70}, using synchrotron irradiation

Research attractiveness of SIO_2 - targets for plasma physics studies

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this material will be represented in a poster presentation by Solovyev A. M.

Liquid silica is one of the major components of geophysically relevant melts (magmas).

Silica finds several industrial applications

Liquid SiO_2 is a prototype of network-forming liquid.

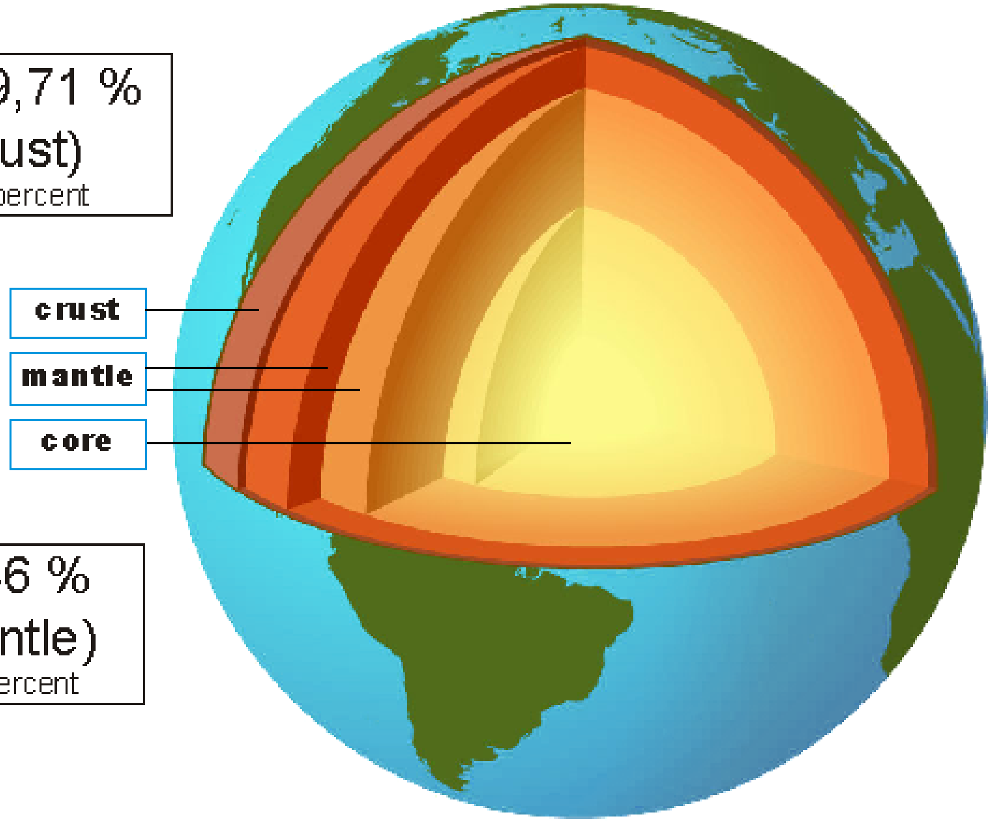
Silica is an working media for developing powerful optical fiber lasers.

Silica aerogel is widely used for inertial fusion targets.

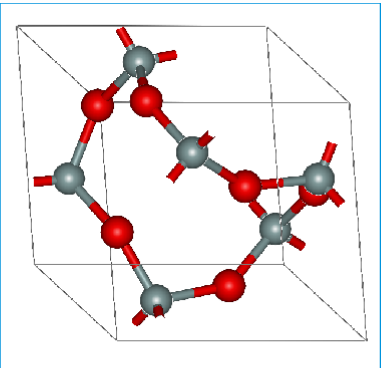
For description of all this processes information for wide P - T area of phase diagram is needed.

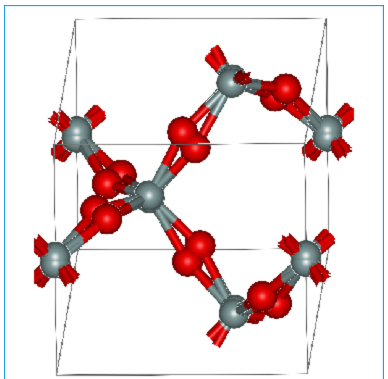
Silica in nature.

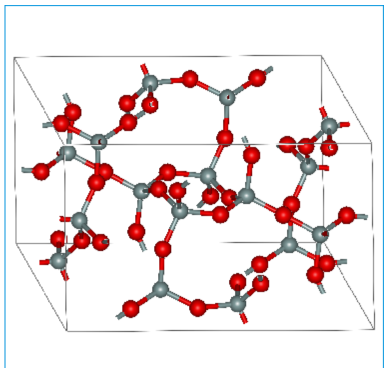
SiO_2 - 59,71 %
(in crust)
in weight percent

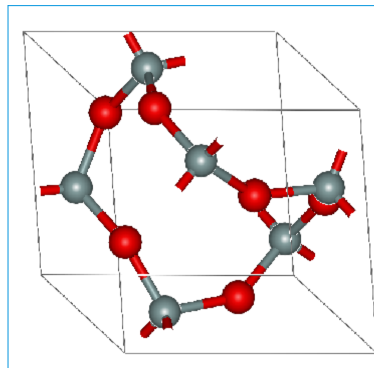


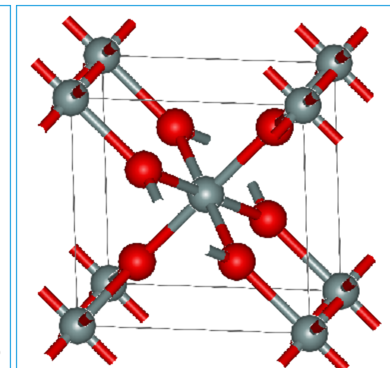
SiO_2 - 46 %
(in mantle)
in weight percent


α-quartz (trigonal crystal)


β-quartz (hexagonal crystal)

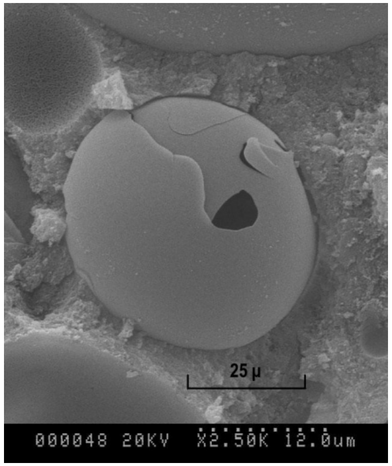

coesite (monoclinic crystal)

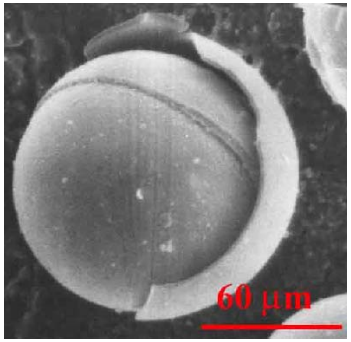

β-tridymite (hexagonal crystal)


stishovite (tetragonal crystal)

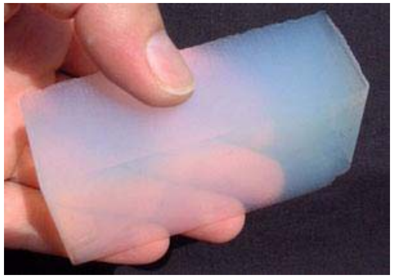
Application of SiO_2 for high energy physics.

Glass Microspheres

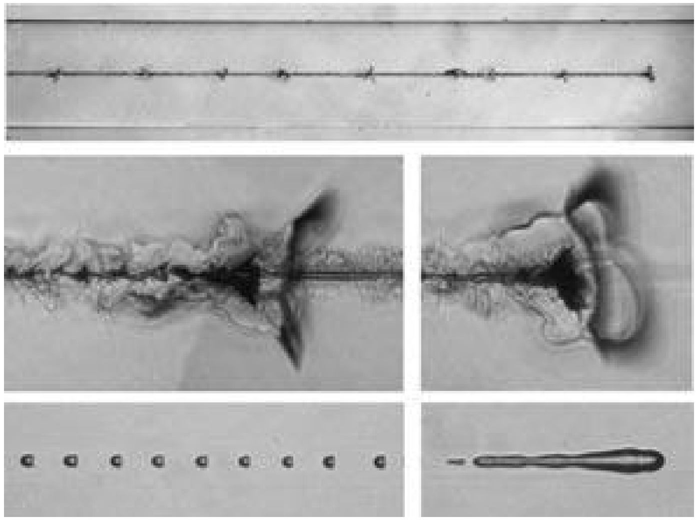




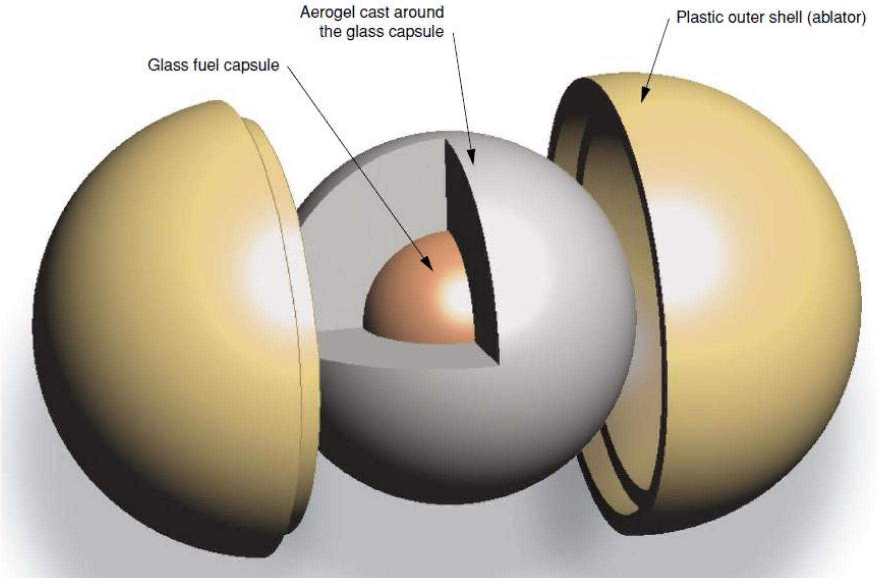
Silica Aerogel



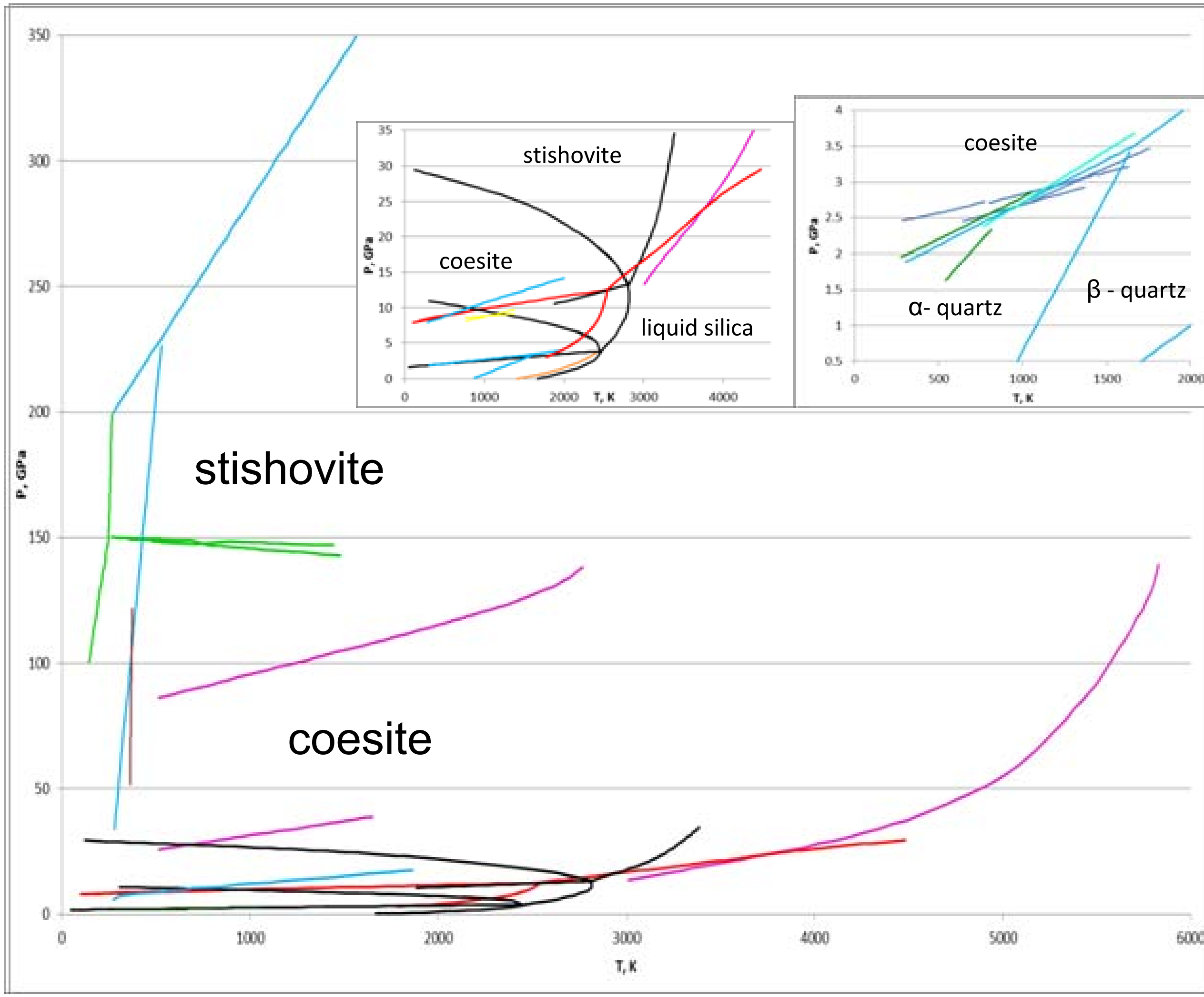
Fiber Fuse Effect



Inertial Confinement Fusion



Phase Diagrams



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- S. I. Akimoto, T. Yagi, and K. Inoue, "High temperature-pressure phase boundaries in silicate systems using in situ x-ray diffraction"; High-Pressure Res.: Appl. Geophys., [Pap. U.S.-Jpn. Jt. Semin.], Honolulu, Hawaii, July 6-9, 1976.
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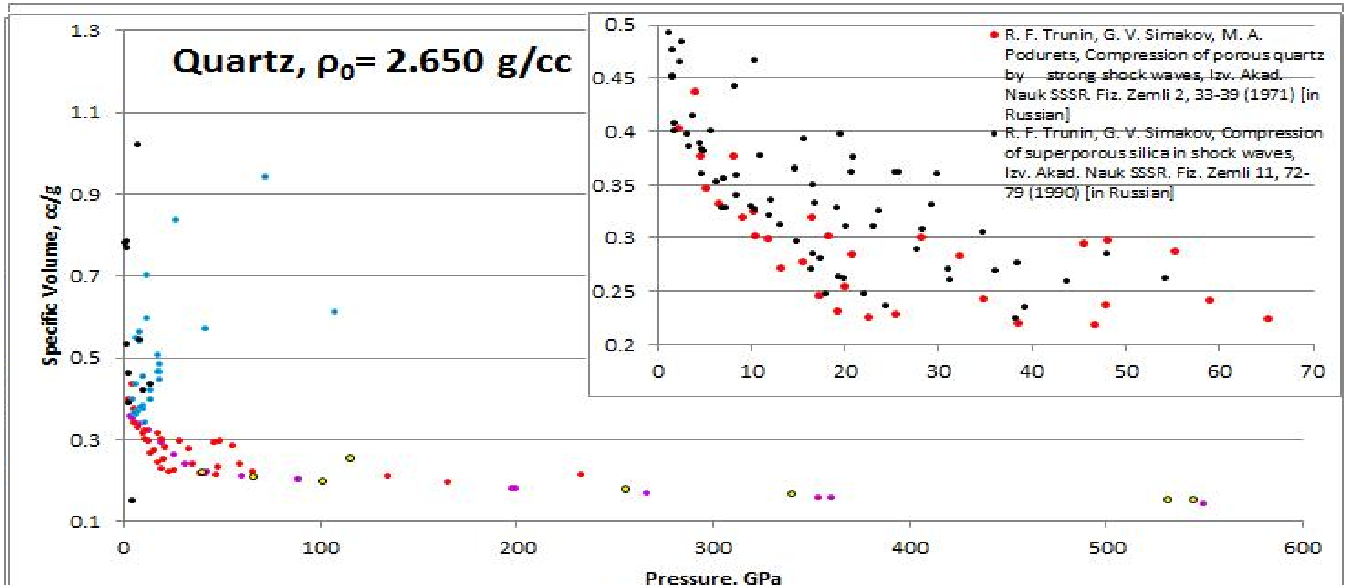
Shock Hugoniot



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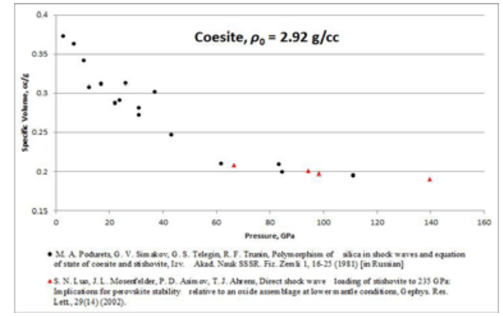
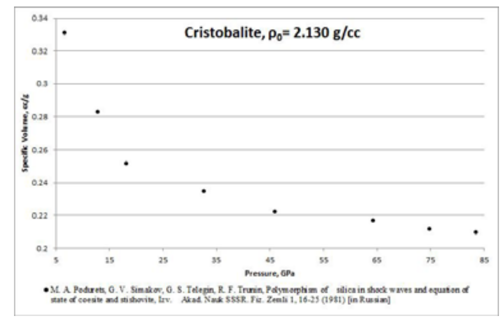
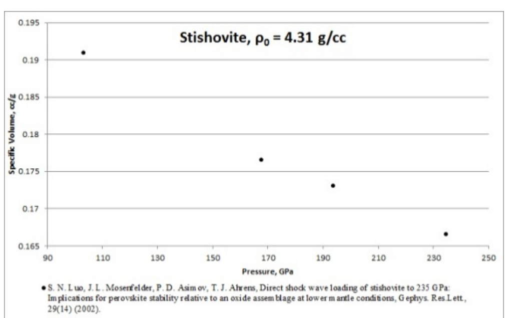
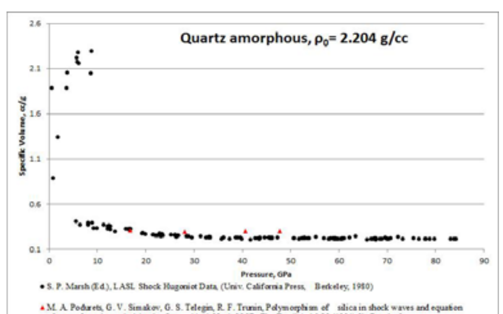
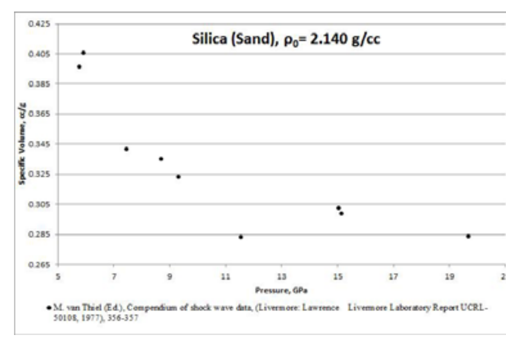


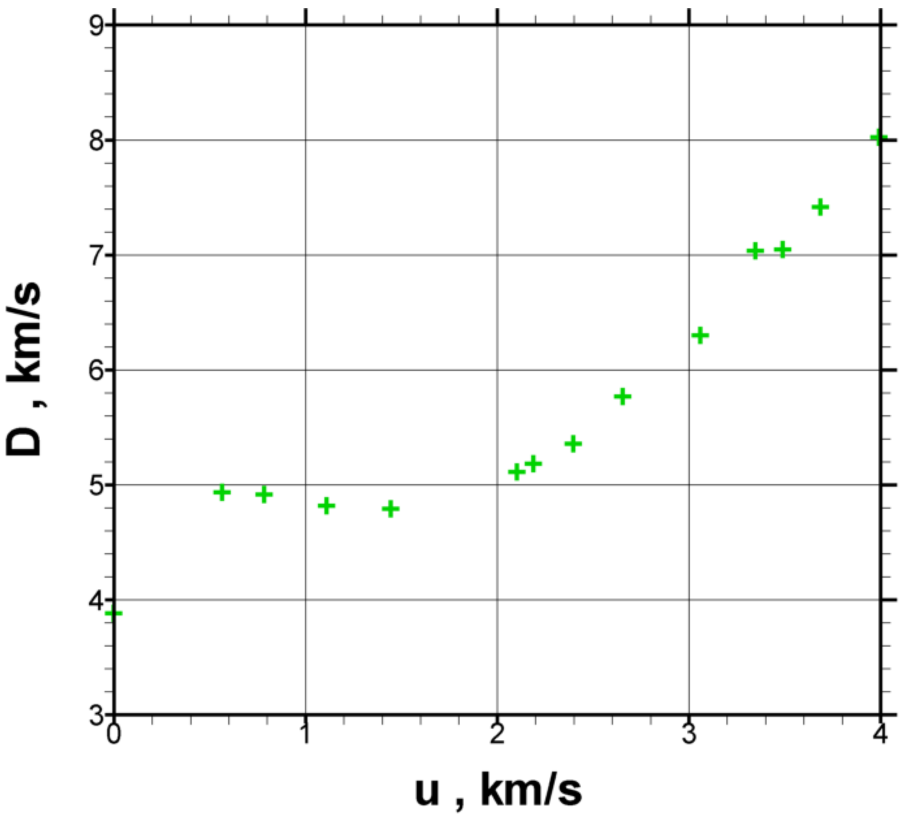


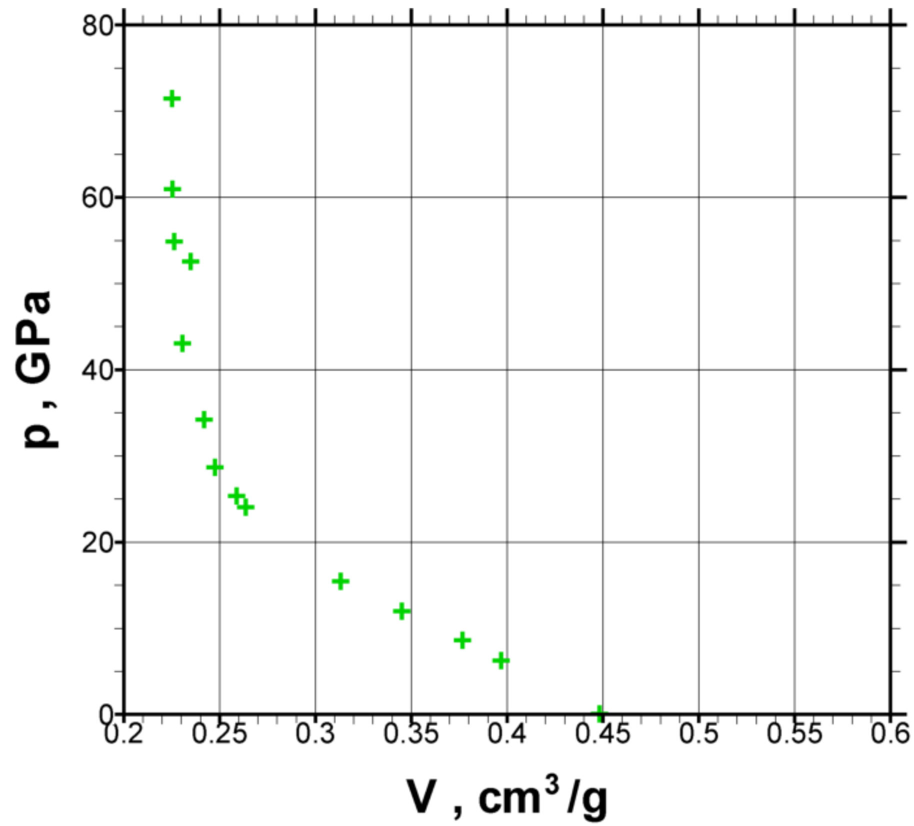






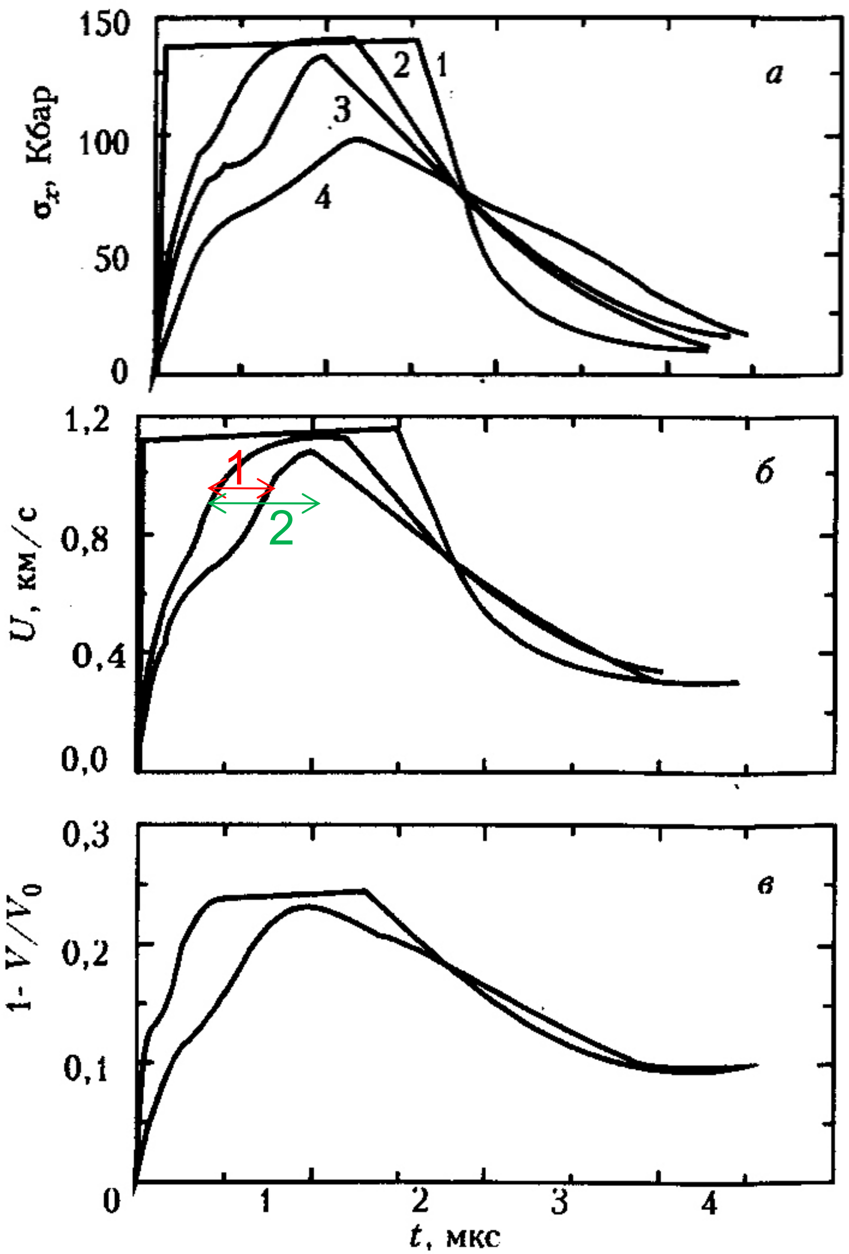
Shock Hugoniot of melted quartz with ρ_o =2.2 g/ccm





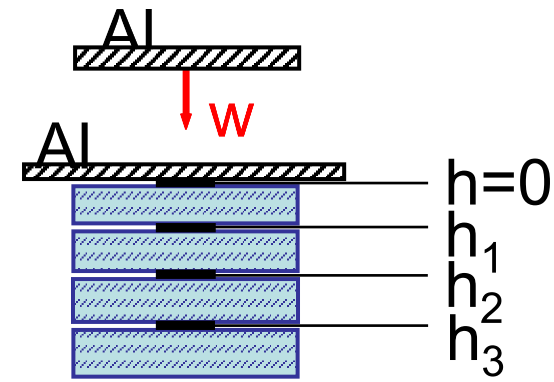
LASL Shock Hugoniot Data / Ed.S.P.Marsh.- Berkeley: Univ. of California Press, 1980, 658p.

Glass К - 8



Tension profiles
Sample thickness:
h_1=0 mm
h_2=6,55 mm
h_3=10,85 mm
h_4=20,7 mm

Particle velocities
h_1=0 mm
h_2= 6,5 mm
h_3=10,5 mm



Relative compression
h_1=3,25 mm
h_2=8,5 mm

Kanel G.I., Rasorenov S.V., and Fortov V.E. Elsevier Science Publishers, 1992

Conclusions:

We found (unexplained by measurement errors) difference in the melting curve of stichovite in the temperature range 2900 K – 4400 K. [1,2,3]

We found a different curve slope of the phase transition coesite – stishovite. [1,2,5]

We found differences in the melting curve of quartz.
(E.g. it reaches a value 2.8 in the range 1600 K - 2300 K). [1,4]

Also it should be noted that there are sparse data at high pressure area as opposed to the area T = 0 – 4000 K, P = 0 – 35 Gpa.

We plan to make revision of phase diagram data in a wide range and investigate unexplored area by experimental ad theoretical methods.

[1] J. Z. Zhang, R. C. Liebermann, T. Gasparik, C. T. Herzberg, and Y. W. Fei, J. Geophys. Res., [Solid Earth], 98 [B11] 19785-19793 (1993).

[2] A. B. Belonoshko, Geochim. Cosmochim. Acta, 58 [6] 1557-1566 (1994).

[3] A. B. Belonoshko, L. S. Dubrovinskii, N. A. Dubrovinskaya, and S. K. Saksena, Petrologiya, 4 [6] 563-580 (1996).

[4] E. Bourova and P. Richet, Geophys. Res. Lett., 25 [13] 2333-2336 (1998).

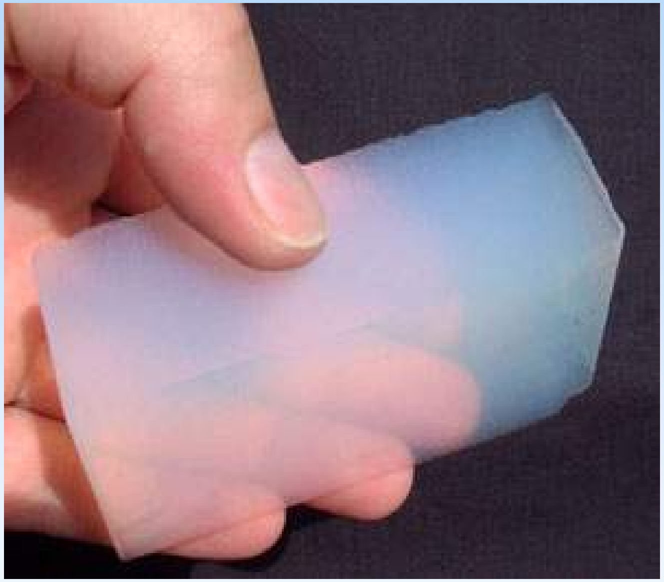
[5] L. S. Dubrovinskii, G. O. Piloyan, and I. D. Ryabchikov, Dokl. Akad. Nauk SSSR, 301 [3] 682-685 (1988).

Investigation of shock compression of SiO_2 – aerogel using synchrotron emission

V.P. Efremov,
K.A.Ten,
E. R. Lukjanchikov,
L. A. Tolochko

Our purpose is investigation of shock wave front structure in porous media

What is it silicon dioxide aerogel ?



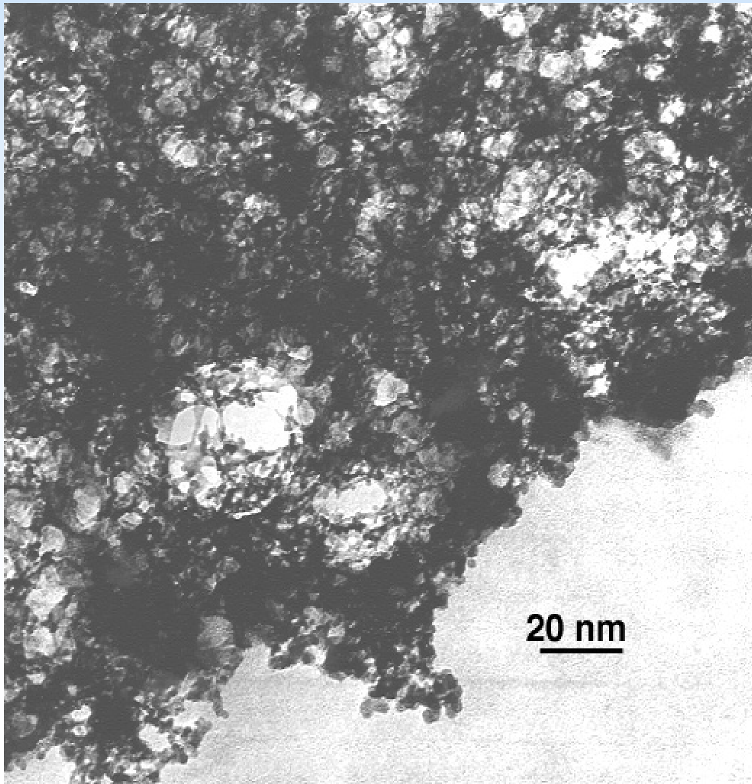
Why aerogel?

1. This is convenient material for porous media model construction

2. This is nanostructure material

3. Good transparency for synchrotron emission

4. Aerogel targets are available in wide interval of densities from 0.01 to 1.0g/cm3.

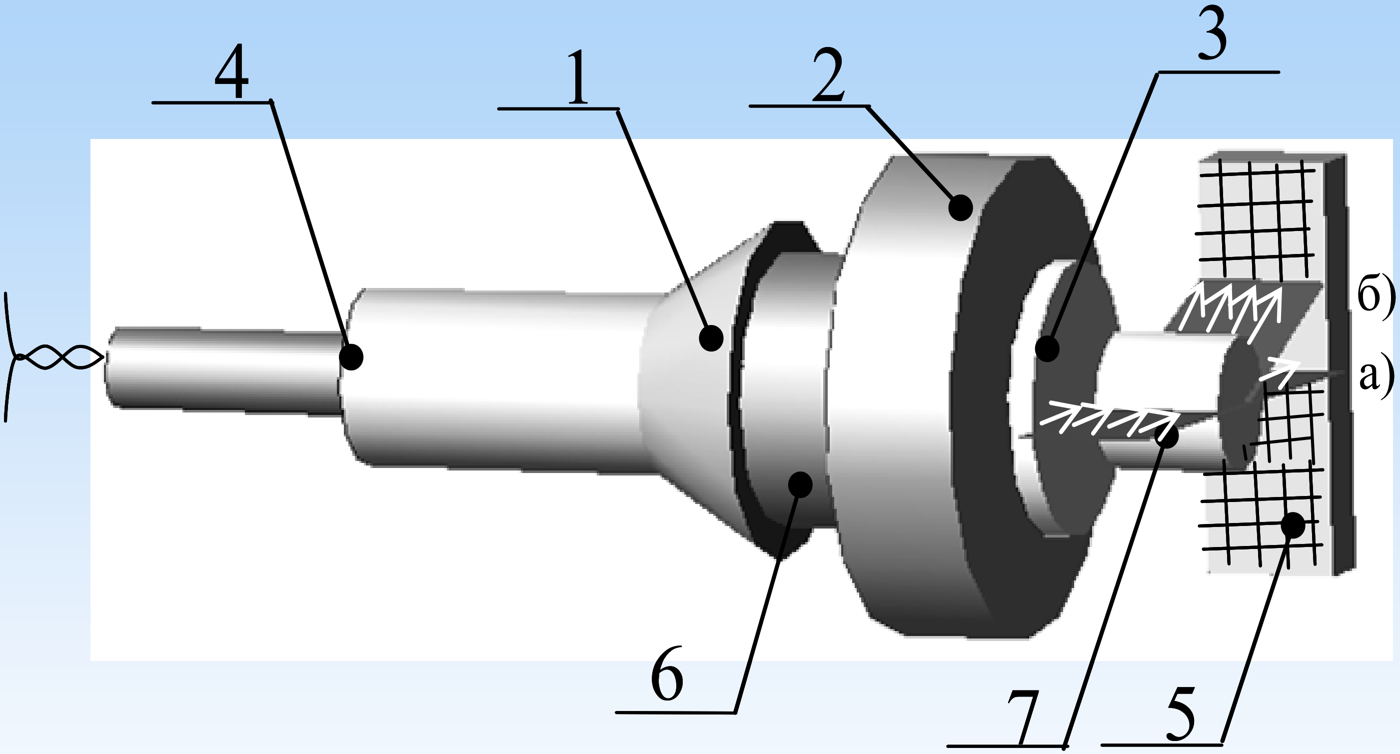


JIHT

SSRC

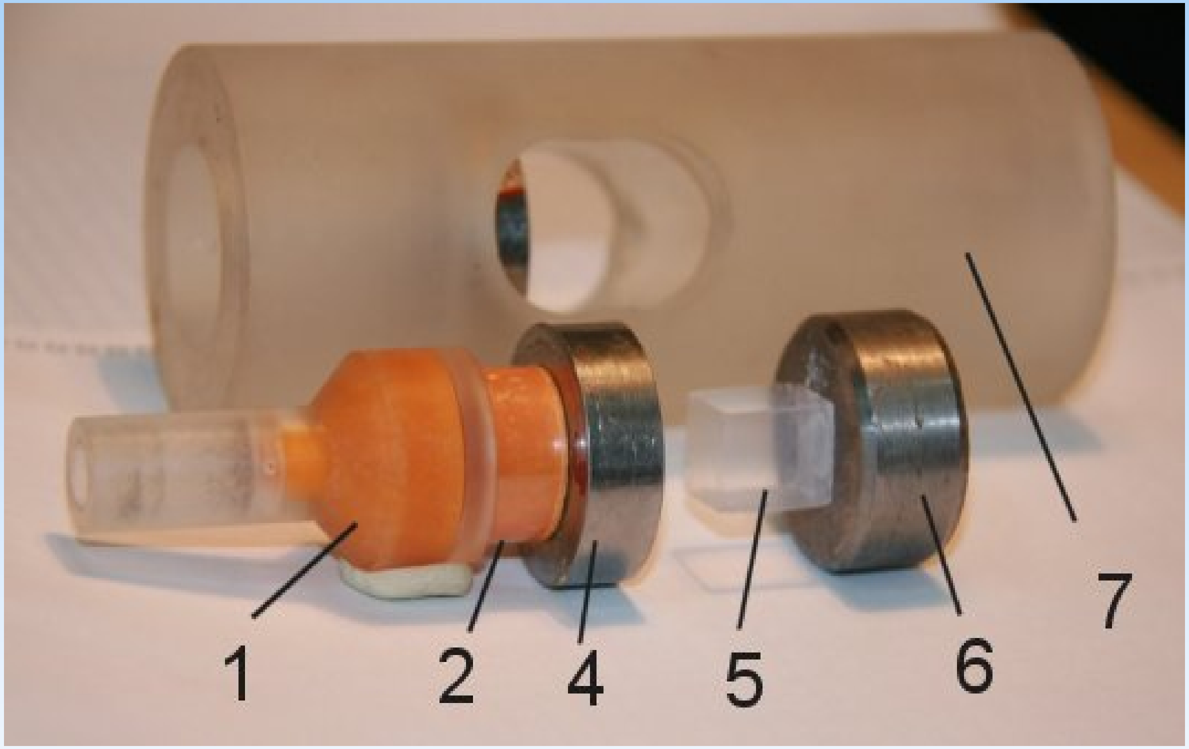
ИГиЛ

Experimental scheme

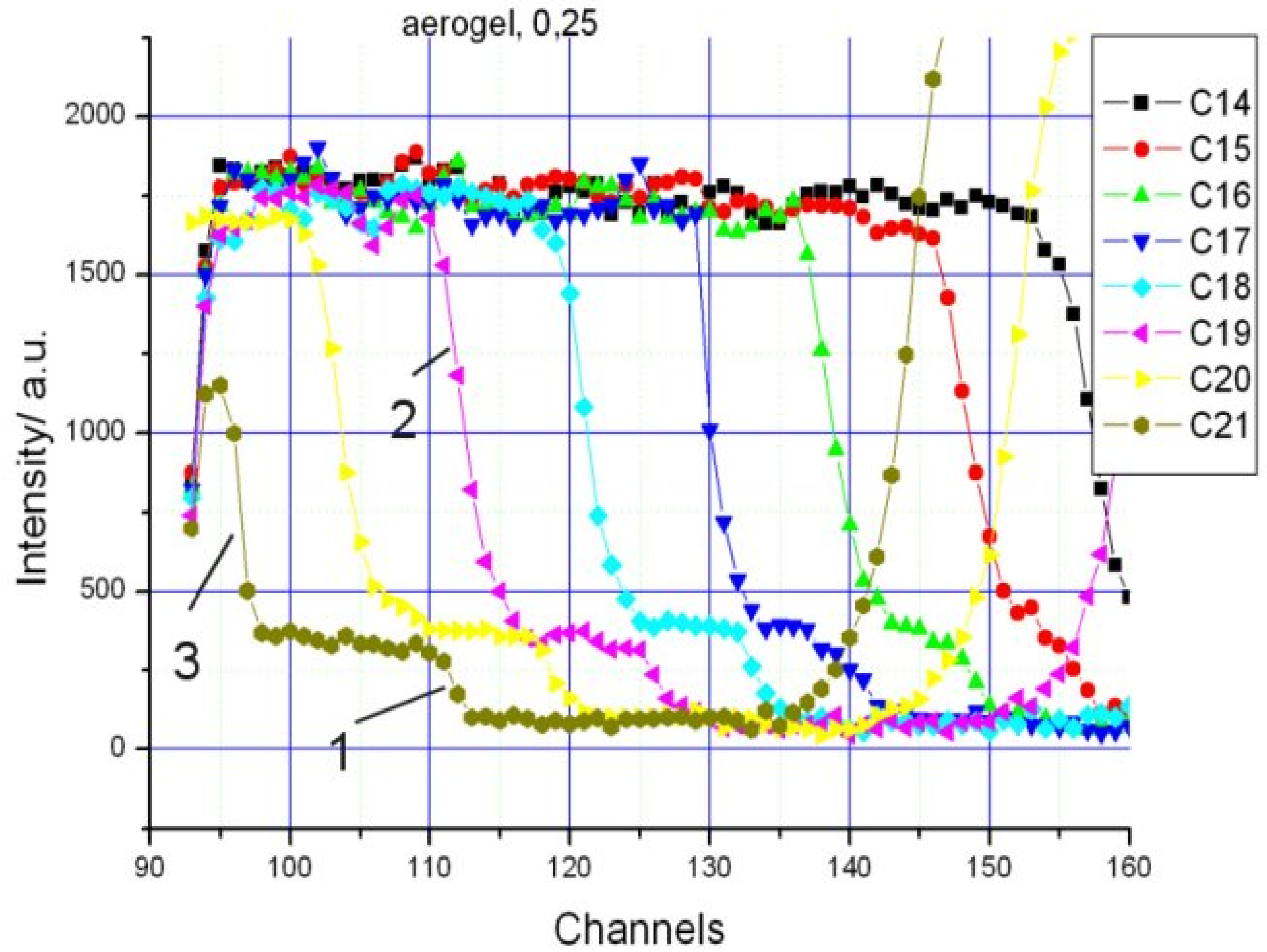


1 – Flat wave generator; 2 - Ring; 3 – Impactor; 4 – Detonator; 5 - detector SI DIMEX; 6 – HE TNT\HMX 50/50; 7 – Investigated target a) – Direct measurement; б) – little angle scattering

Experimental design

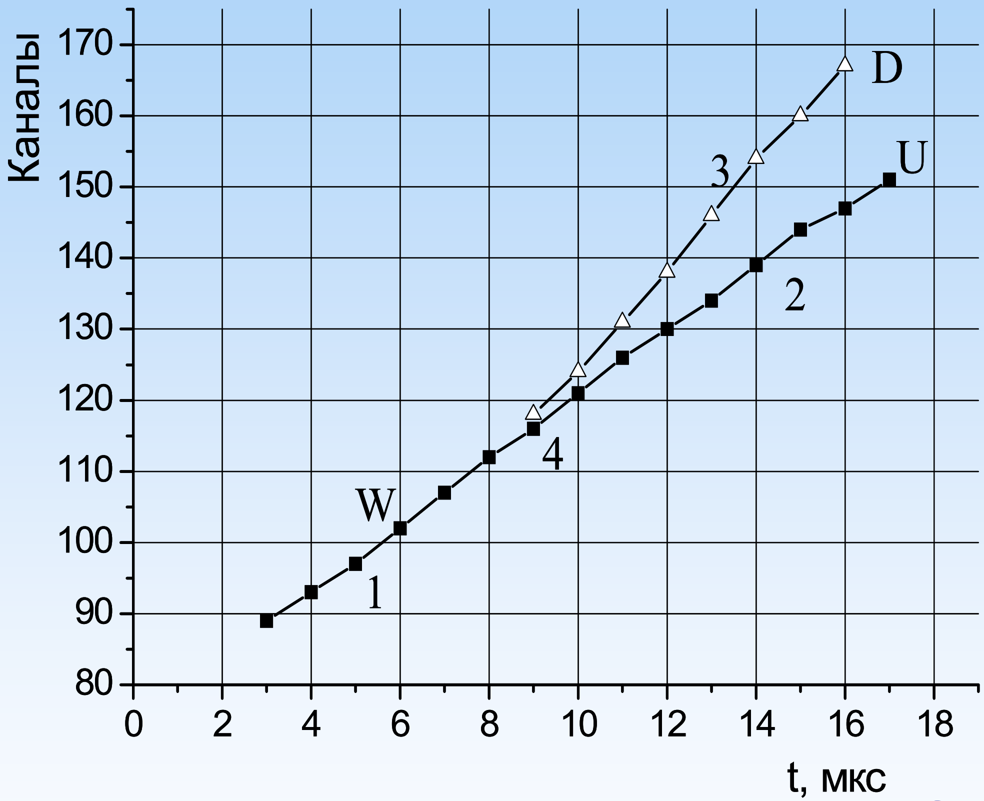


1 – Flat wave generator; 2 –explosive; 4 –Impactor; 5 – aerogel, 6 – Steel; 7 – Carcass – PMMA



Measurement of synchrotron radiation passed target

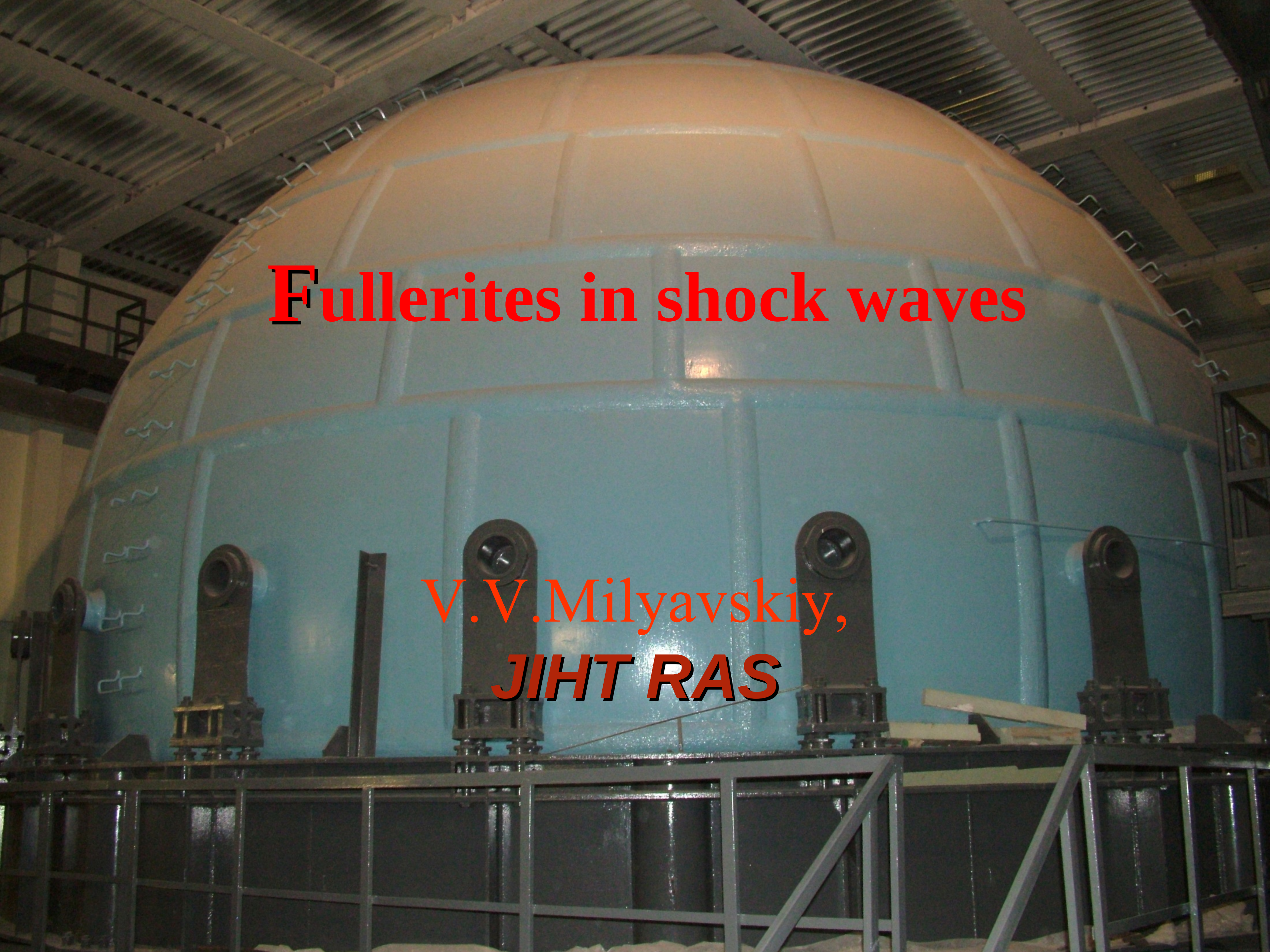
Experimental X-t diagram

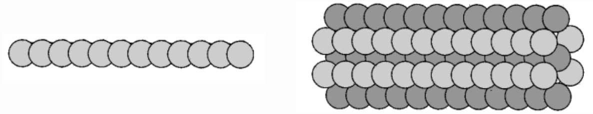


1 – Impactor; 2 – Boundary between impactor-aerogel; 3-Shock wave in aerogel; W=0,45 km/s; 4 –Collision time; U = 0,44 km/s; D = 0,66 km/s

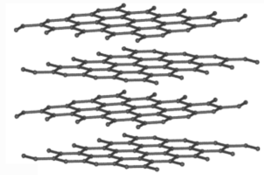
Fullerites in shock waves

V.V.Milyavskiy,
JIHT RAS



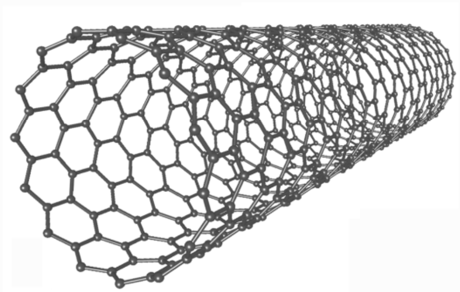


Carbynes

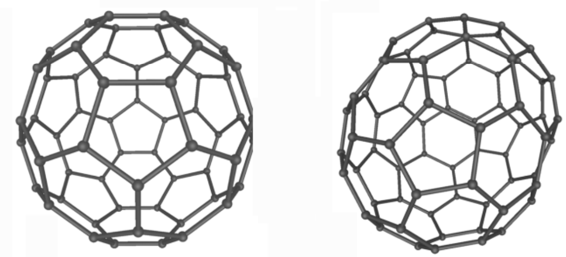


Graphites

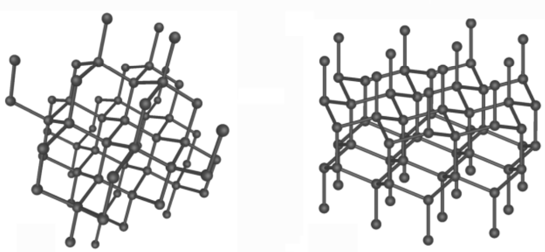
Graphene



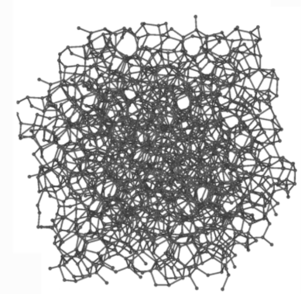
Carbon Nanotubes



Fullerenes, Fullerites and Fullerene-based polymers

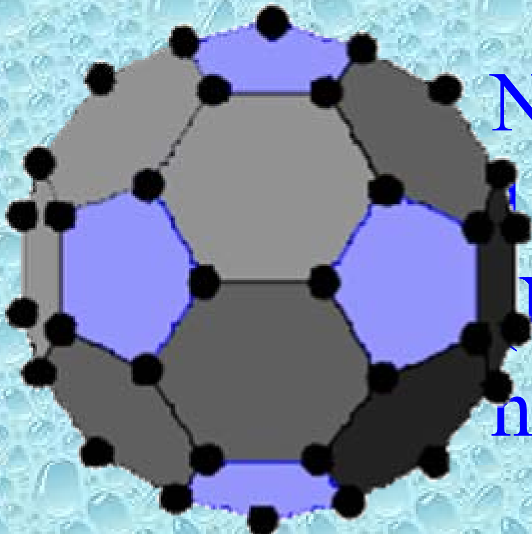


Diamonds

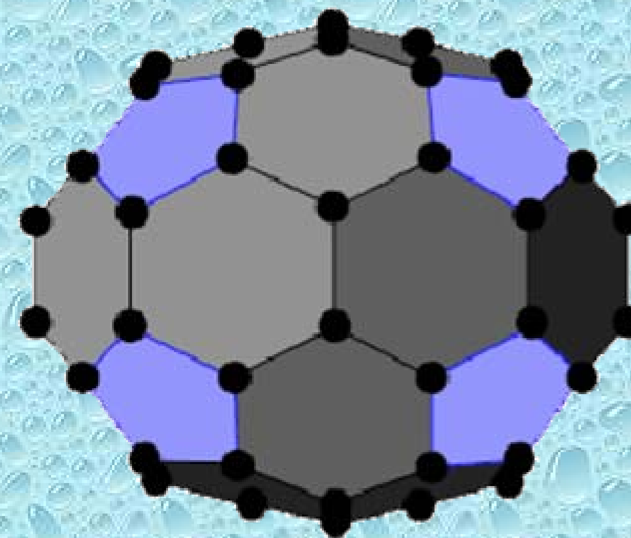


Amorphous Carbon

What is "FULLERENES" ?



$N \geq 22$;
12 pentagons;
$(N-20)/2$ hexagons



C_{22}, C_{24}, C_{26}, C_{28}, C_{30}, C_{32}, C_{34}, C_{36}, C_{38} .....

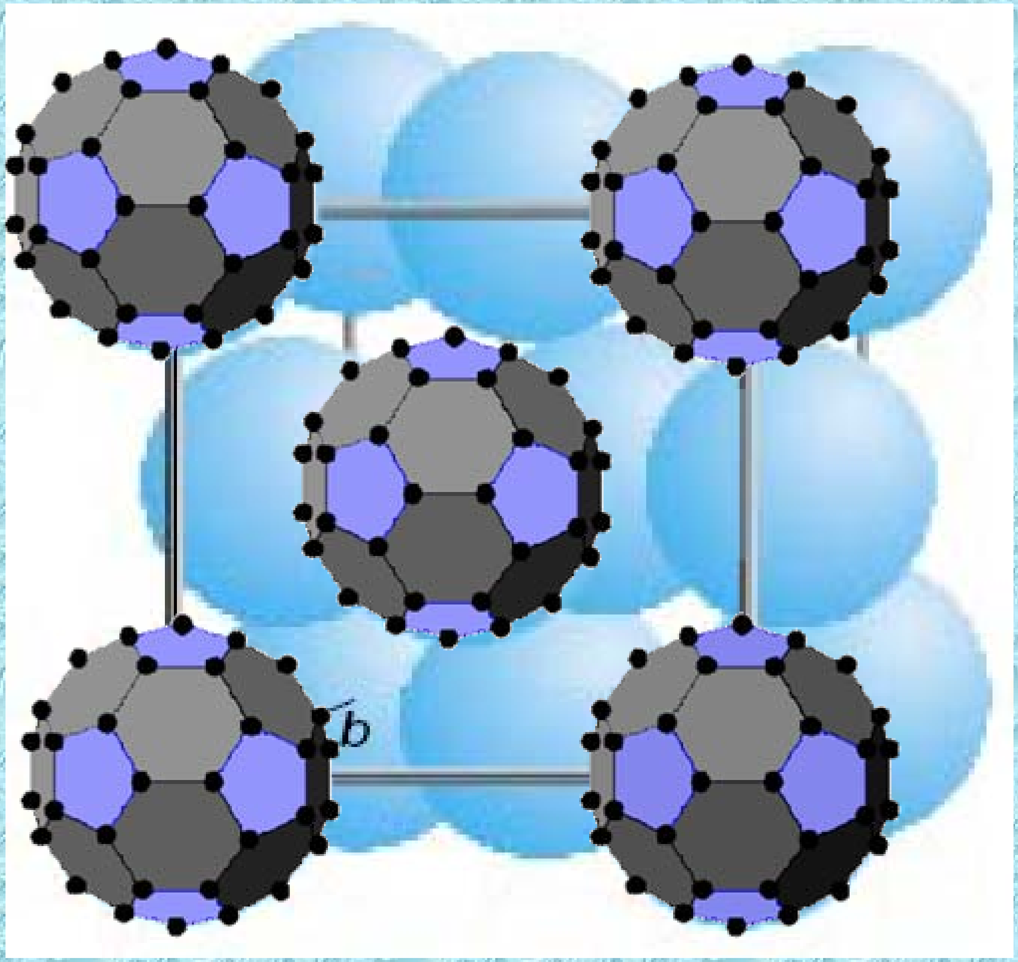
↓

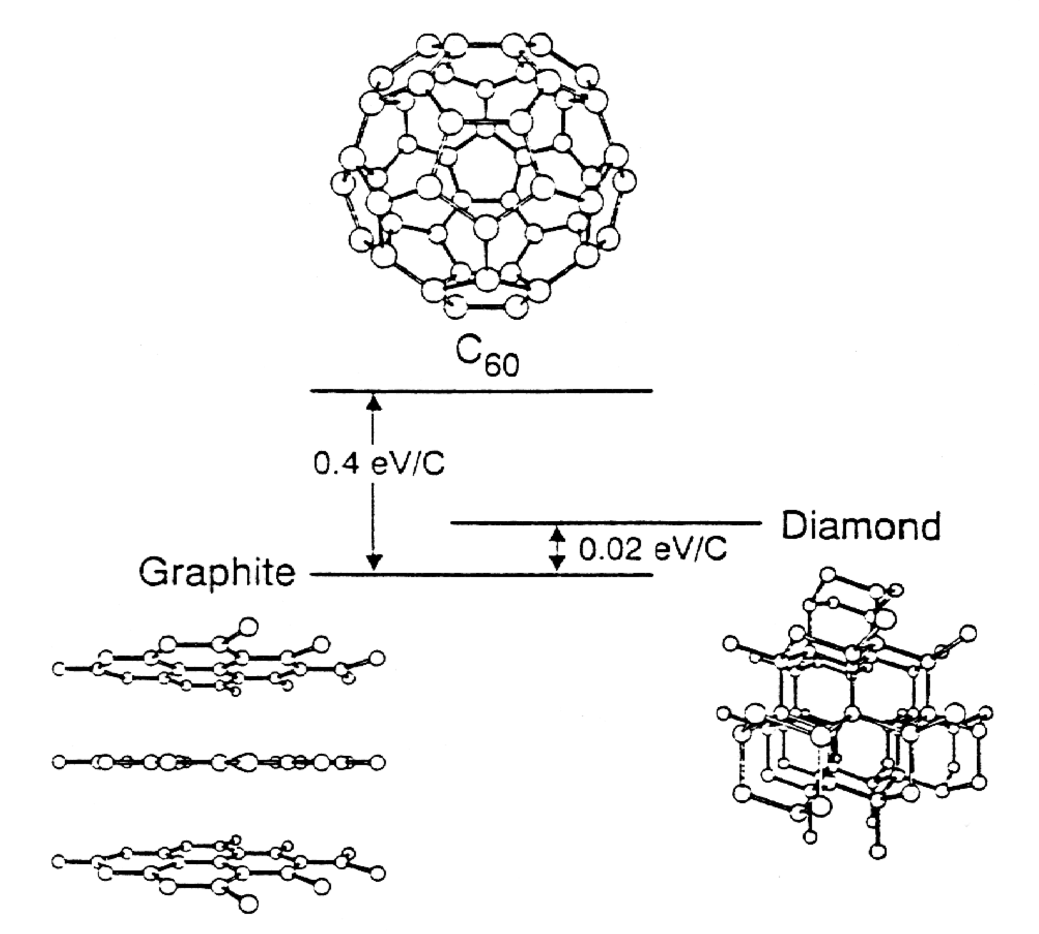
the rule of isolated pentagons

↓

C_{60}, C_{70}, C_{72}, C_{74}, C_{76}, C_{78}, C_{80}, C_{82}, C_{84} .....

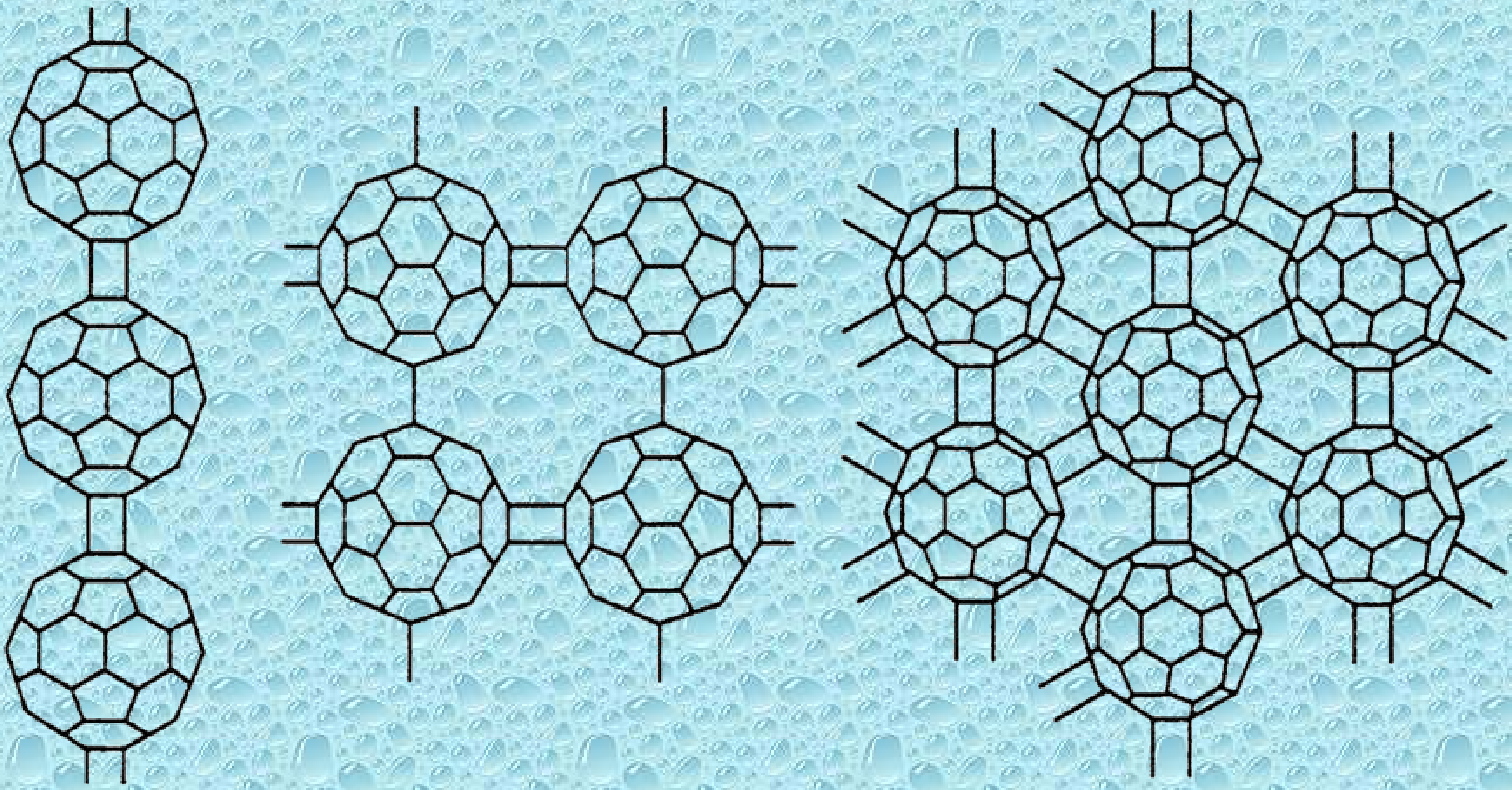
FCC-structure of C_{60} fullerite





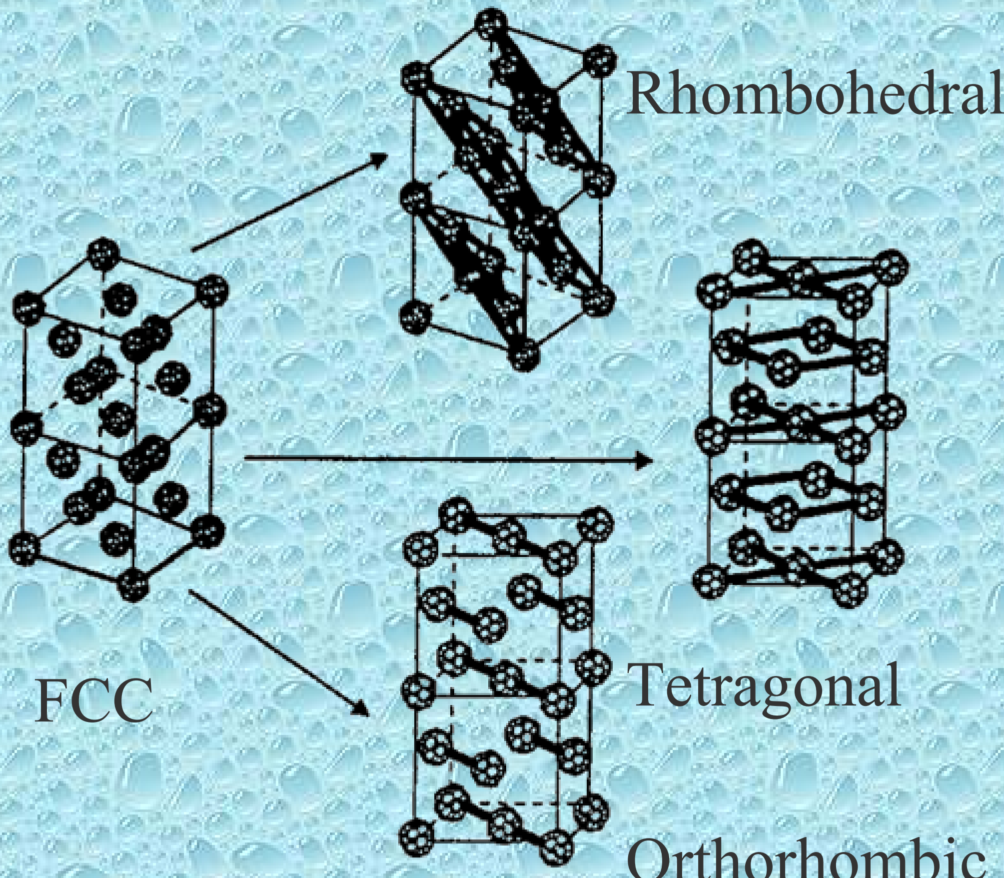
The enthalpy of formation of C_{60} is 3270 kJ/kg*, C_{70} – 3069 kJ/kg**. This energy should be released during transformation of fullerites to graphite. It is comparable with the heat of explosion of ammonite – 4312 kJ/kg.

*Kolesov V. P. et al. J. Chem. Thermod. 28 (1996) 1121.
*Lebedev B. V. et al. Thermochimica Acta 299 (1997)127.
*Zubov V.I. (private communication)
**Herminio P. Diogo et al. J. Phys. Chem. Sol. 58 (1997)1965.



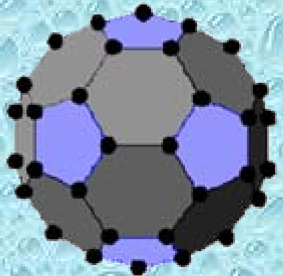
1D- and 2D- polymerized structures of C_{60} fullerite

V.V. Brazhkin, A.G. Lyapin: Usp. Fiz. Nauk 166 (1996) 893.

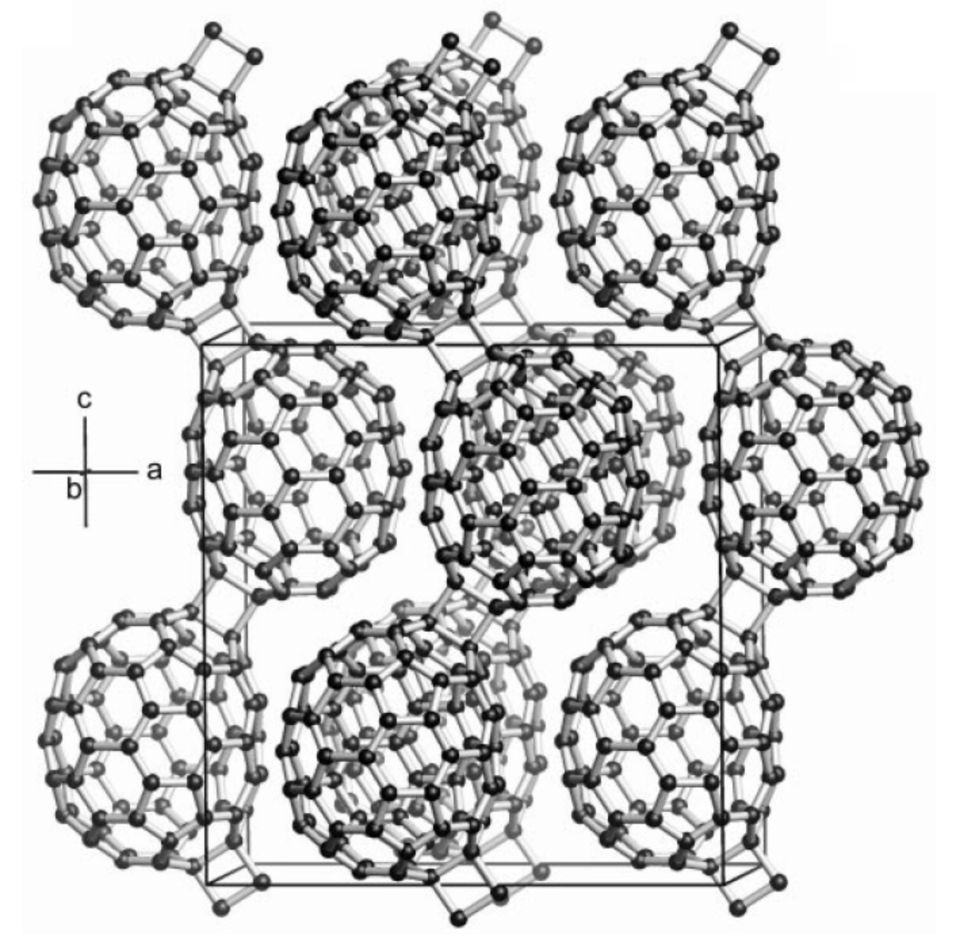


Crystal-geometrical conformity between starting C_{60} and polymerized C_{60} phases.

B. Sundqvist: Advances in physics. 48 (1999) 1.

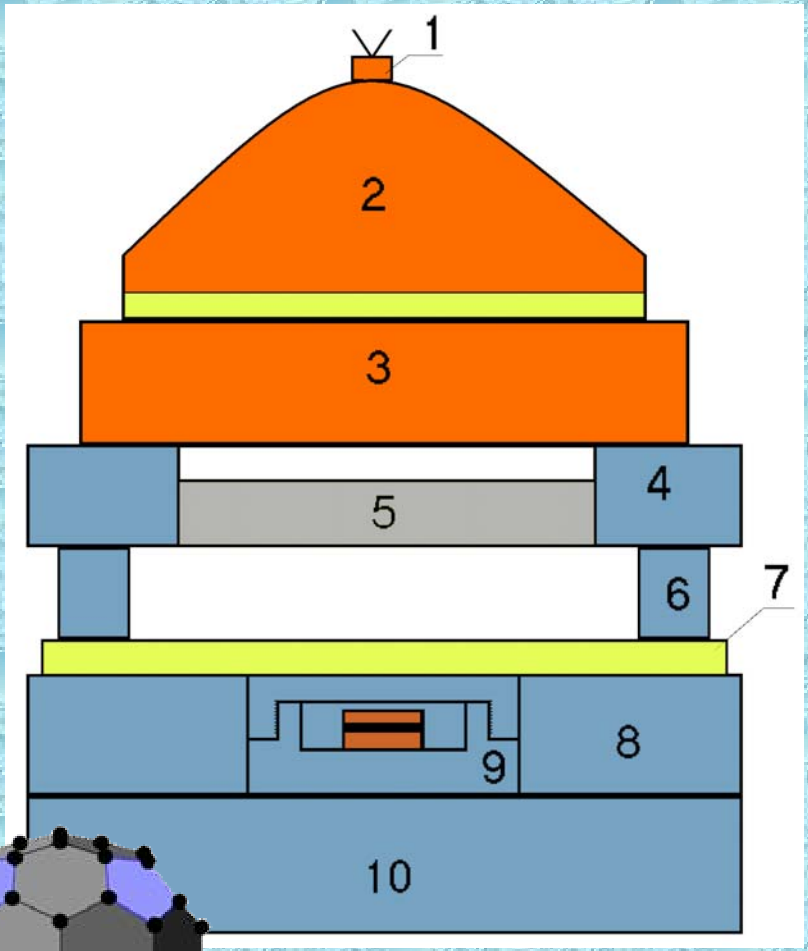


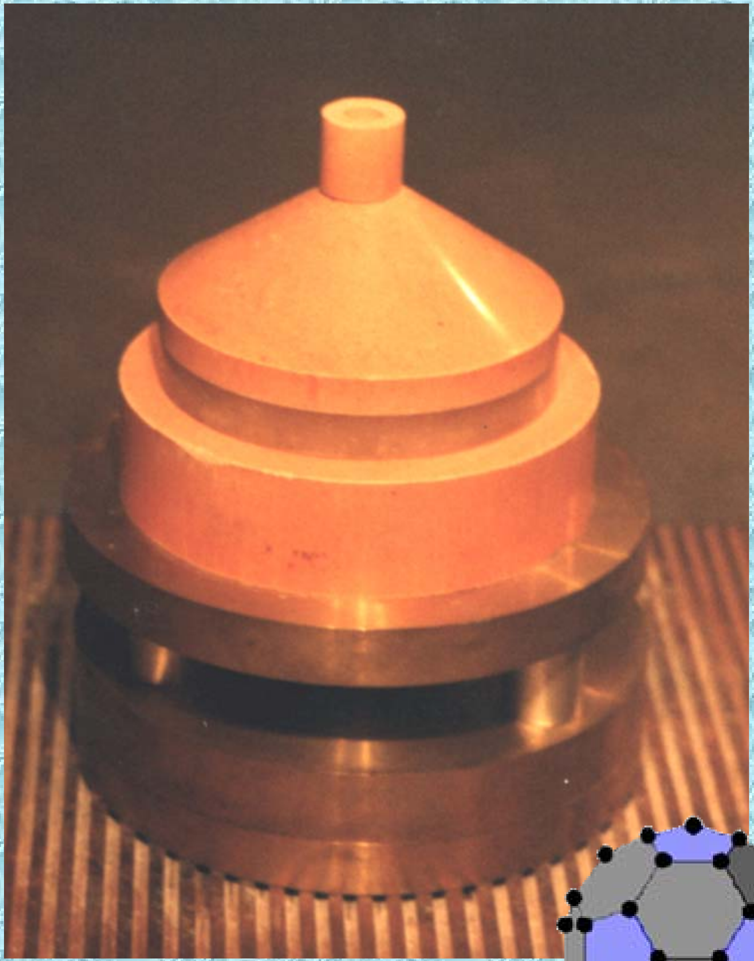
1D Orthorhombic polymer of C_{70}

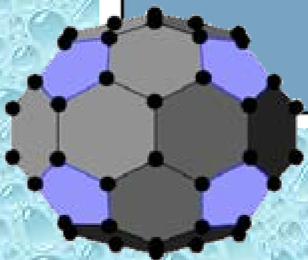


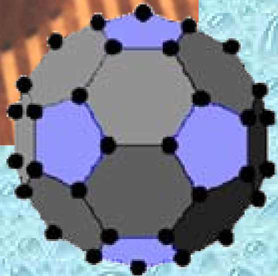
Alexander V. Soldatov, *et al.* Topochemical Polymerization of C_{70} Controlled by Monomer Crystal Packing *Science* 293, 680 (2001).

Comparative microstructural studying of samples recovered after shock wave loading of C_{60} and C_{70} fullerites





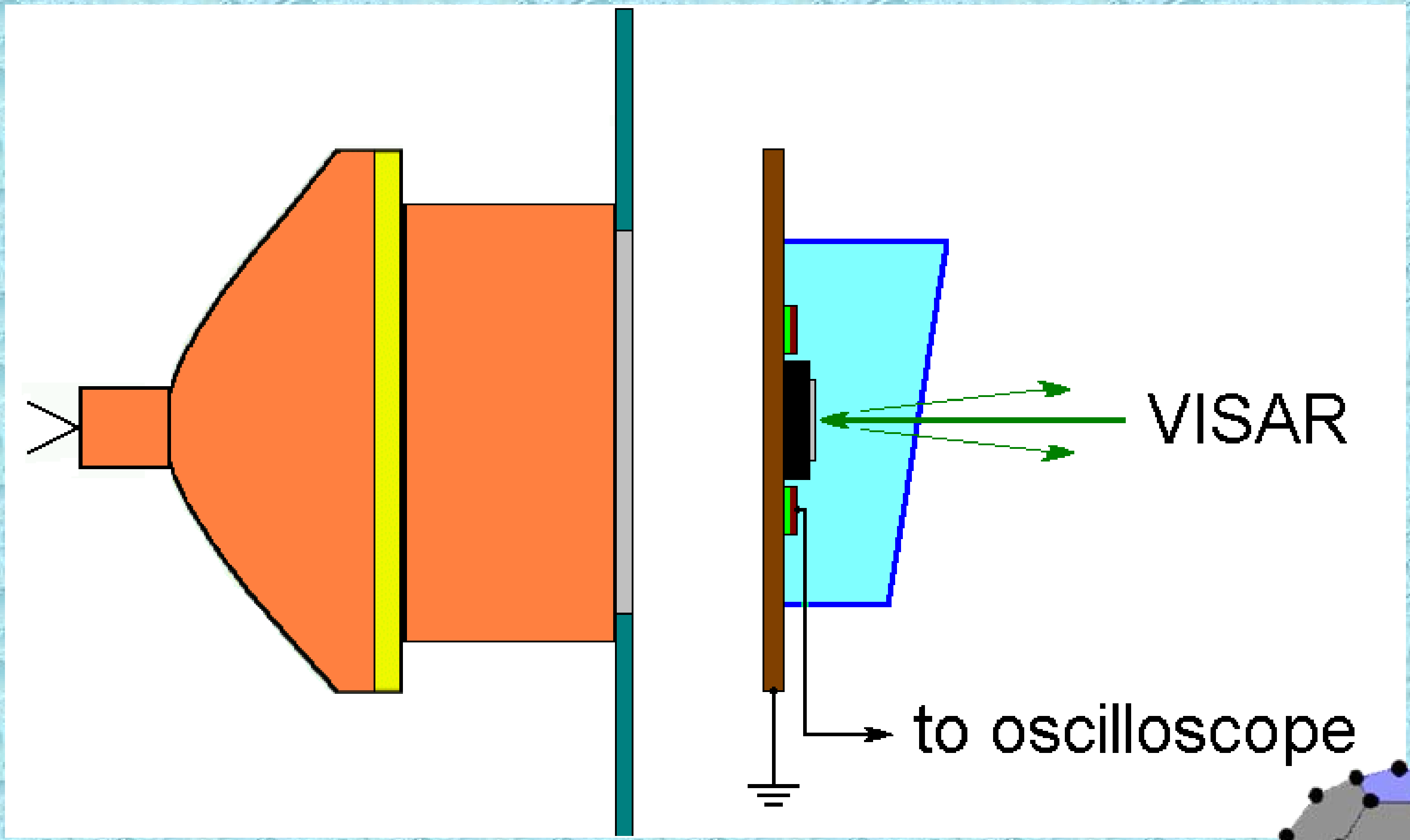




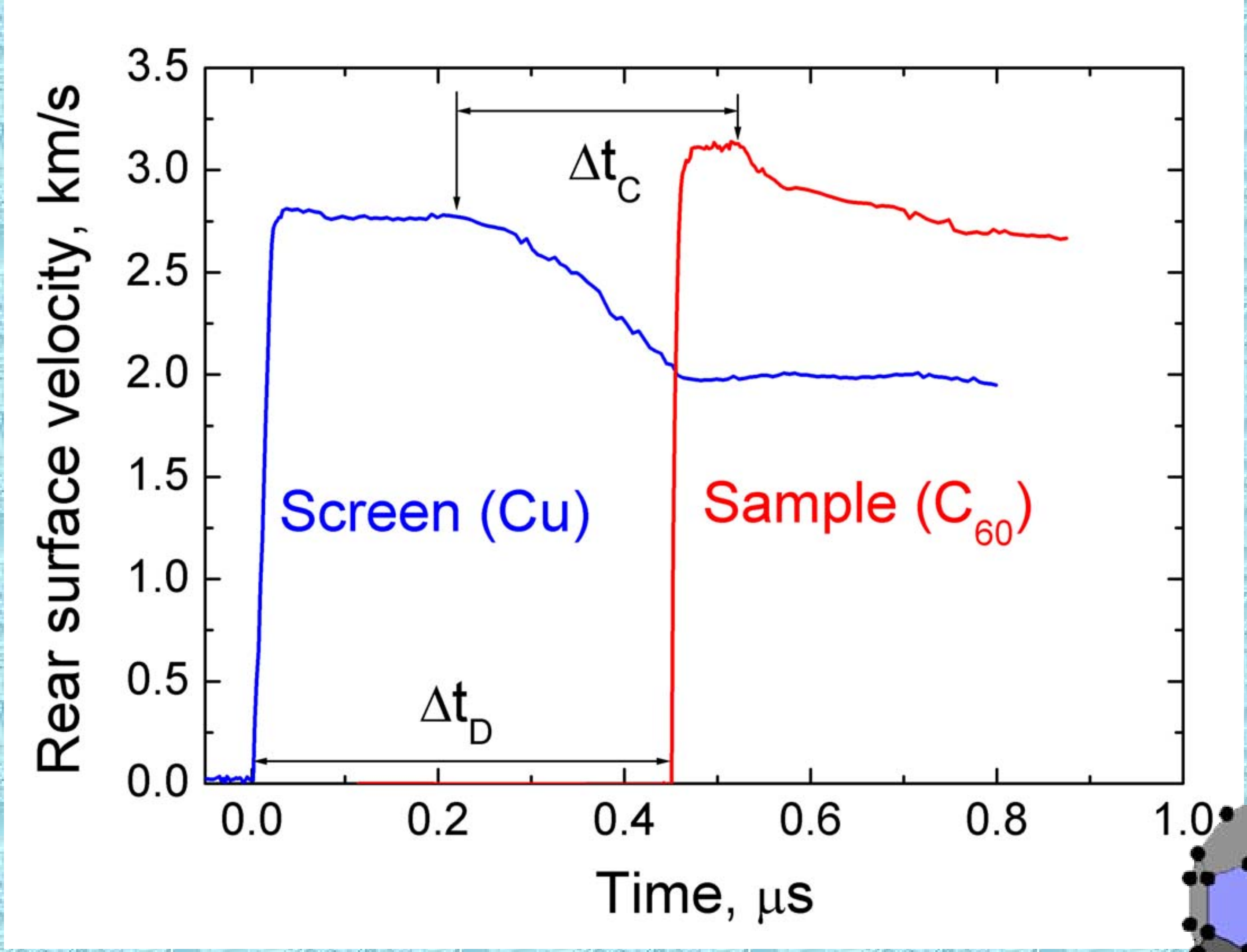
Shock compressibility and sound velocities in shock-compressed C_{60} fullerite

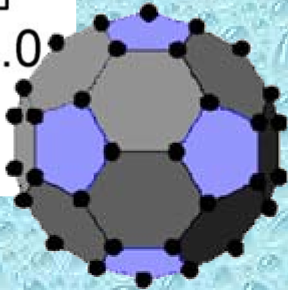
Joint Institute for High Temperatures of RAS, Moscow
Institute for Problem of Chemical Physics of RAS, Chernogolovka
RFNC All-Russia Research Institute of Experimental Physics, Sarov

Experimental assembly

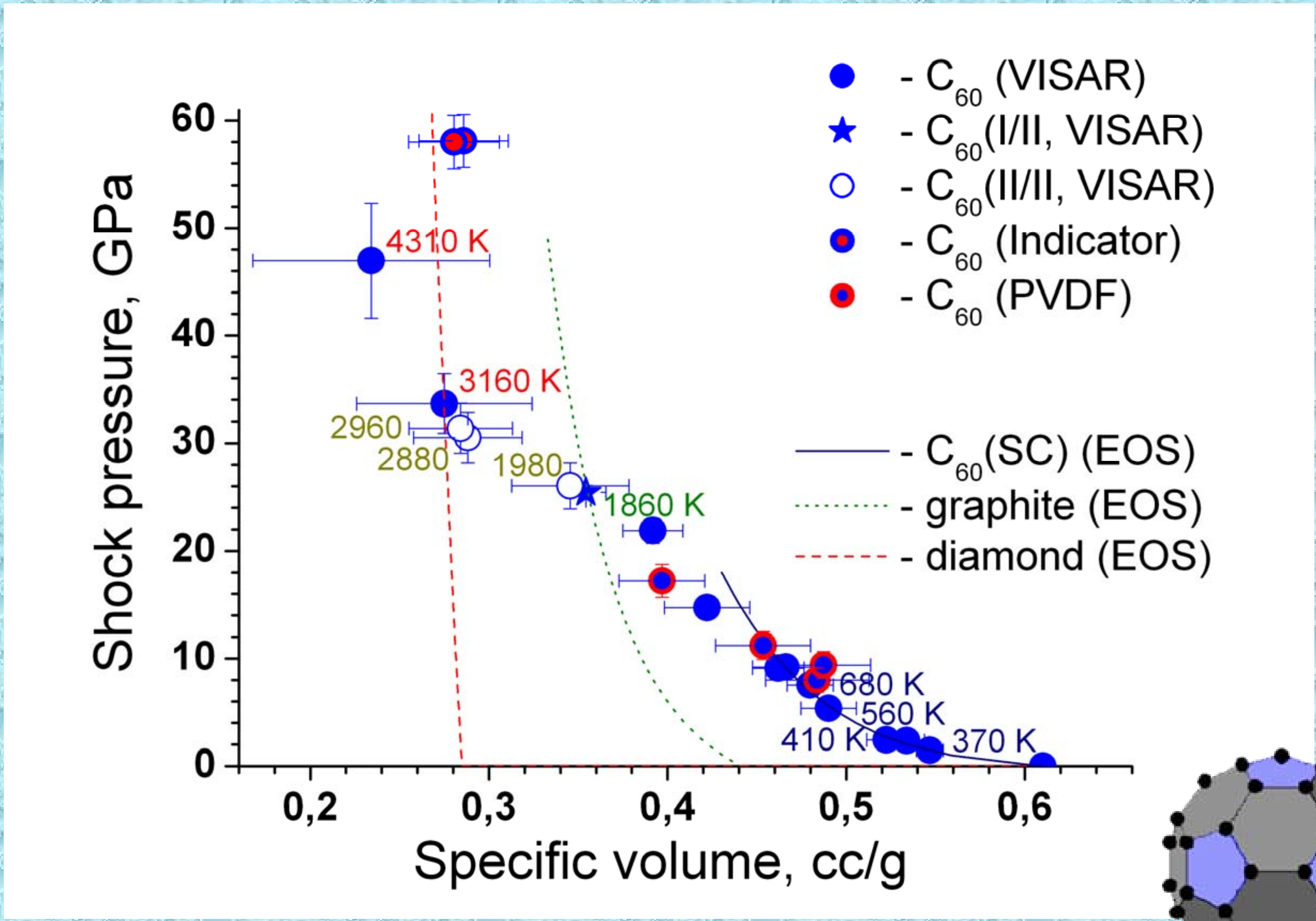


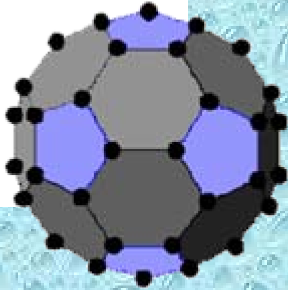
Experimental profiles



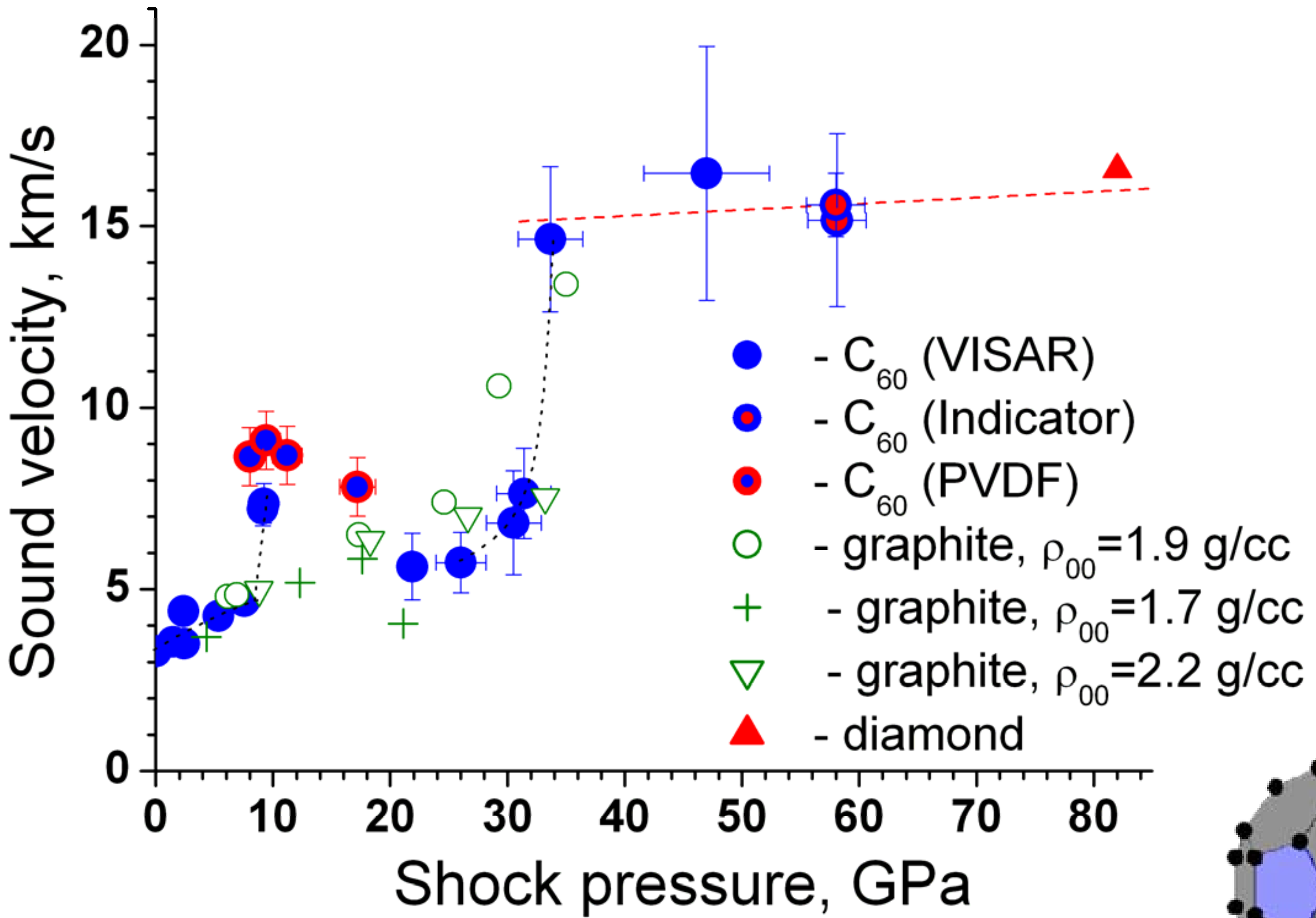


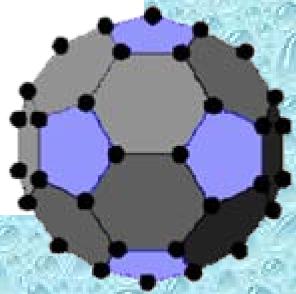
Shock Compressibility of C_{60} fullerite



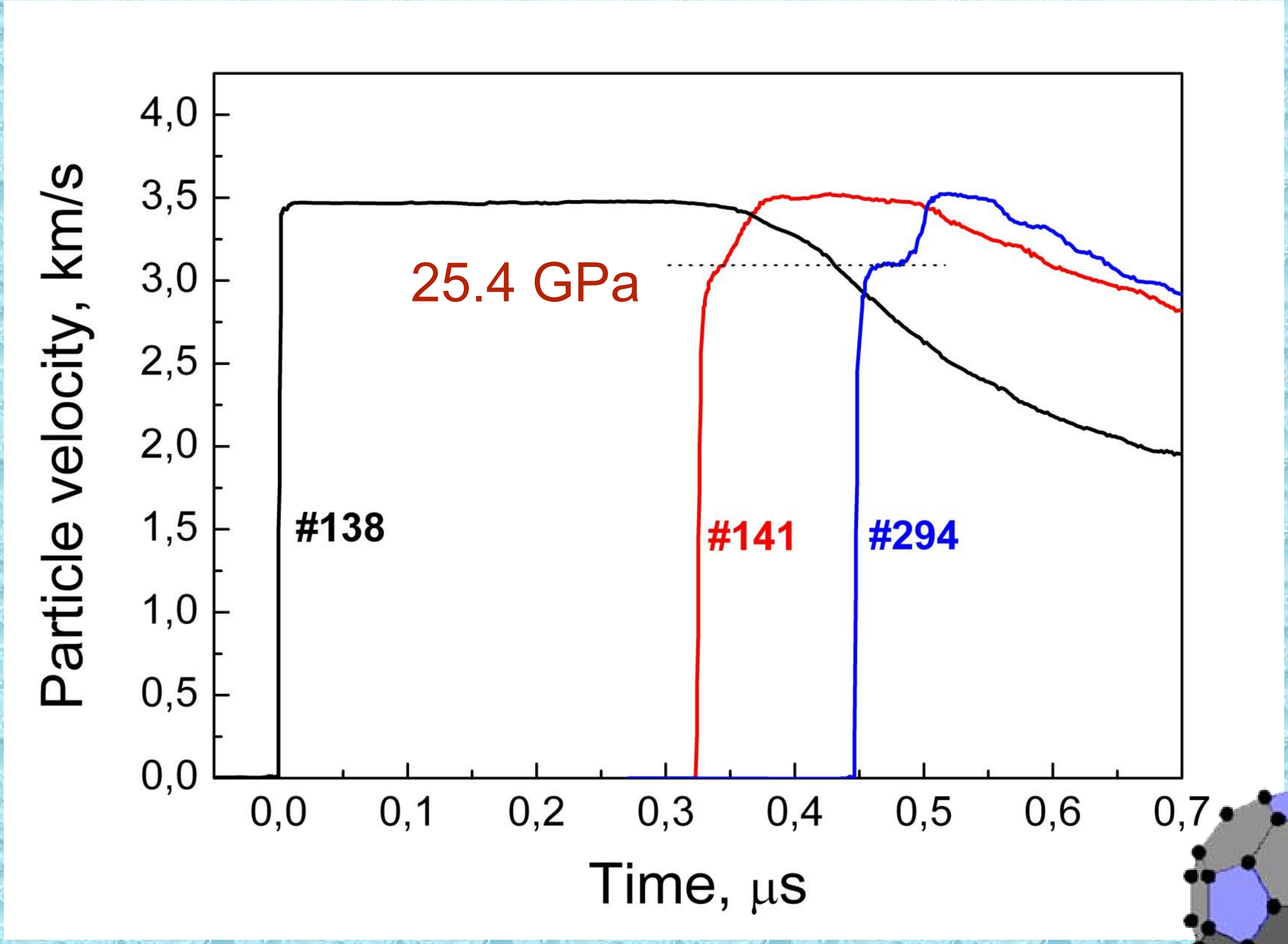


Sound velocity in shocked C_{60}

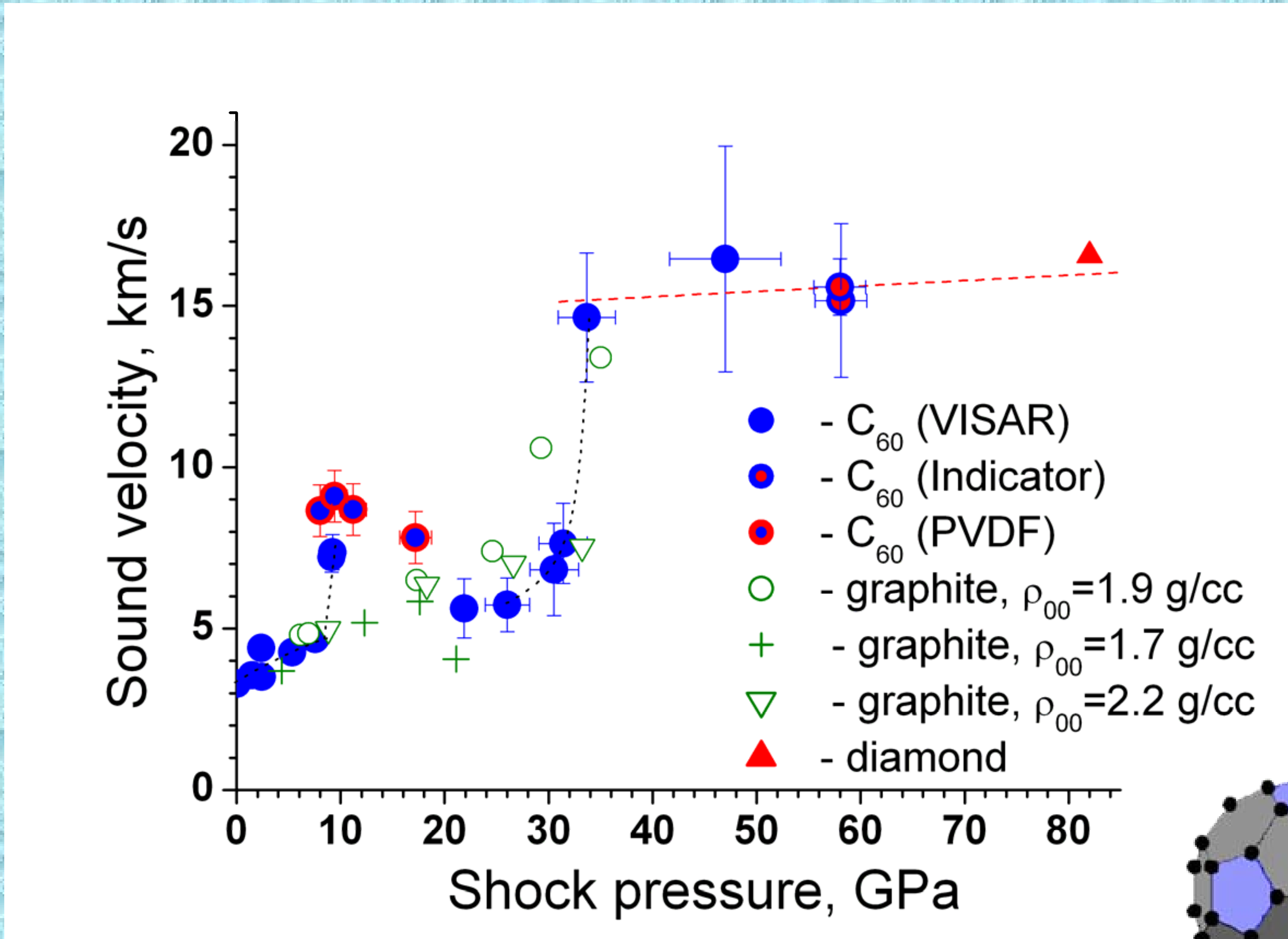


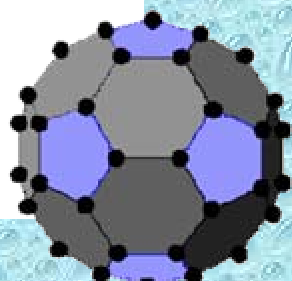


“Two-wave” structure of the shock front



Sound velocity in shocked C_{60}

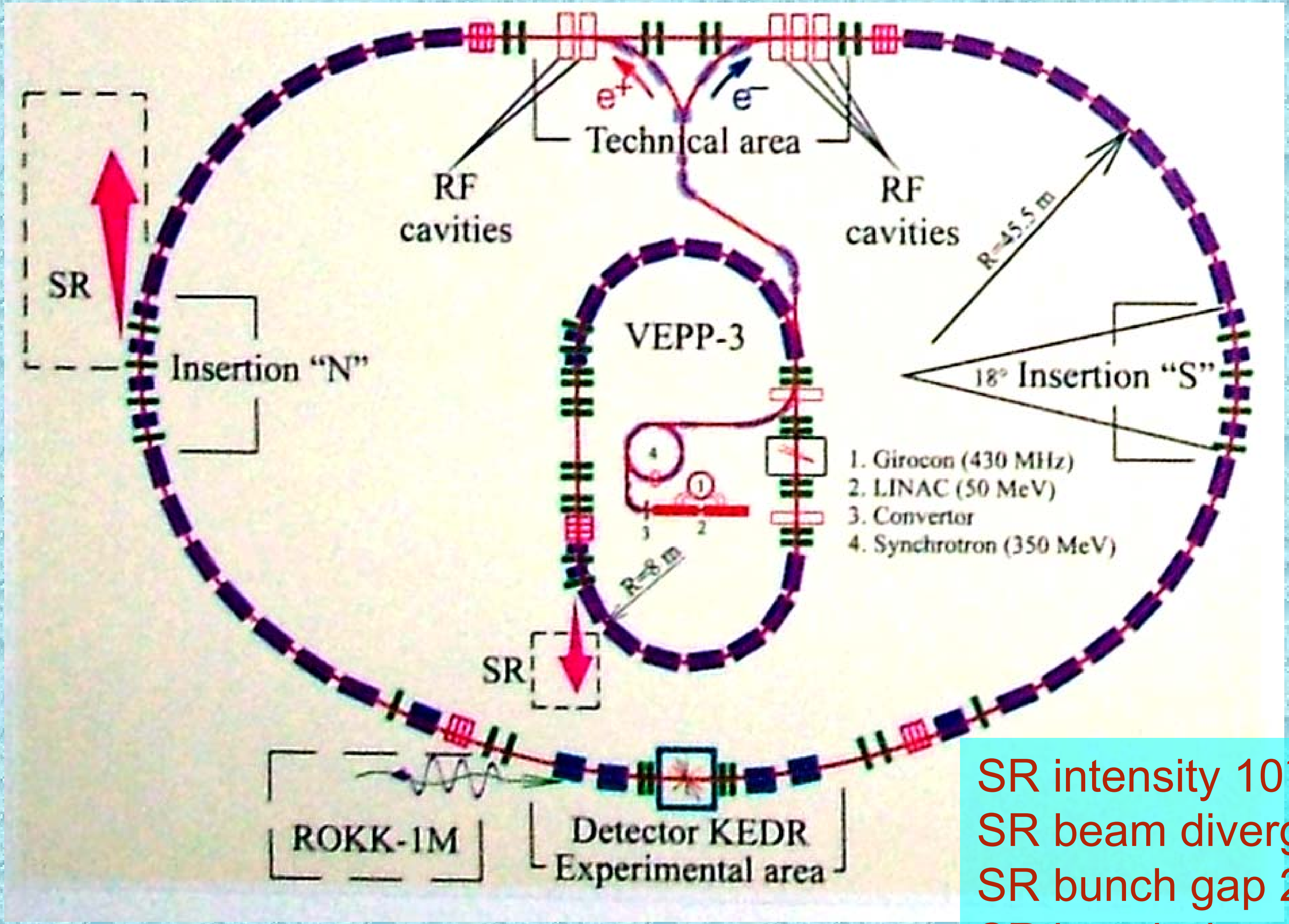




Shock compressibility of C_{70} fullerite

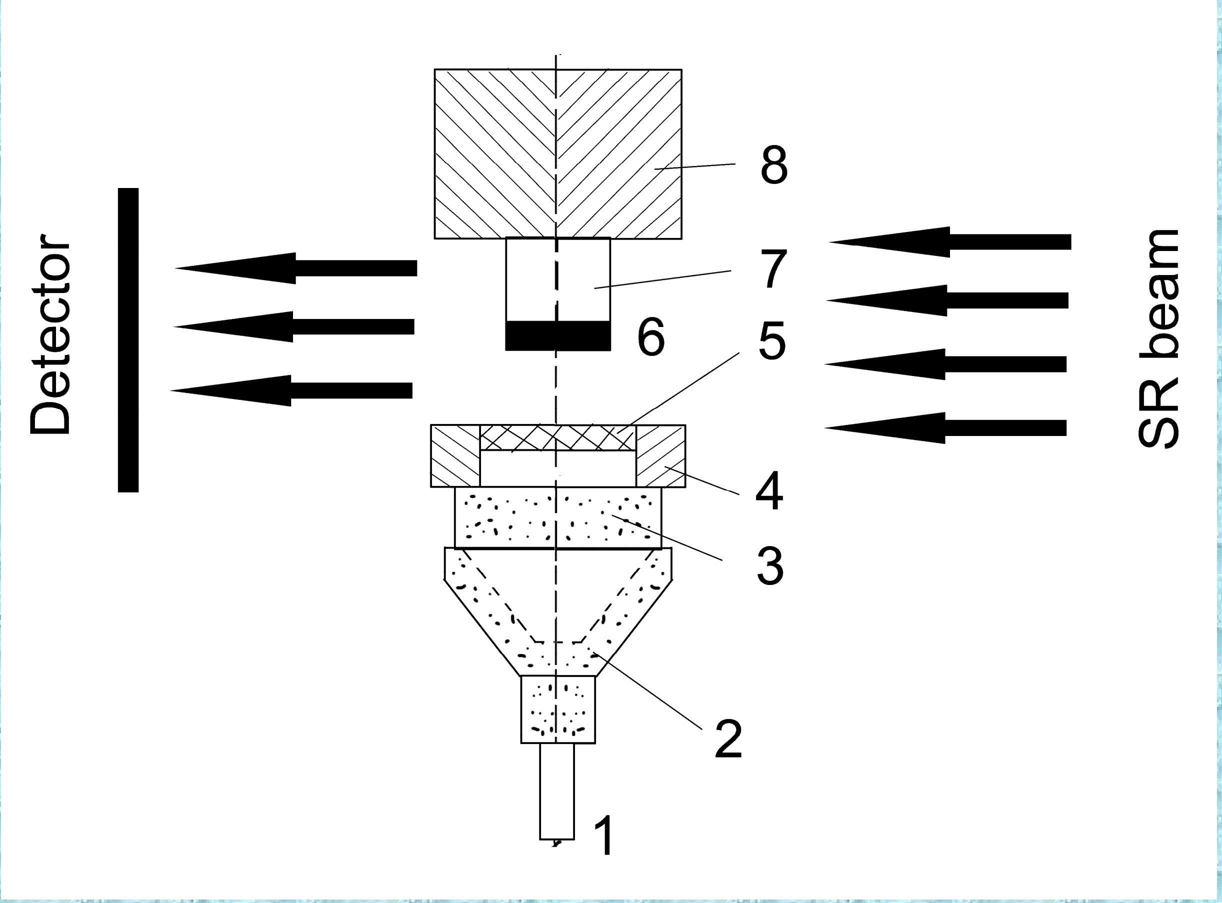
Joint Institute for High Temperatures of RAS, Moscow
Institute of Nuclear Physics SB RAS, Novosibirsk
Lavrentyev Institute of Hydrodynamics SB RAS, Novosibirsk

Pulsed-periodical SR source of Institute of Nuclear Physics SB RAS



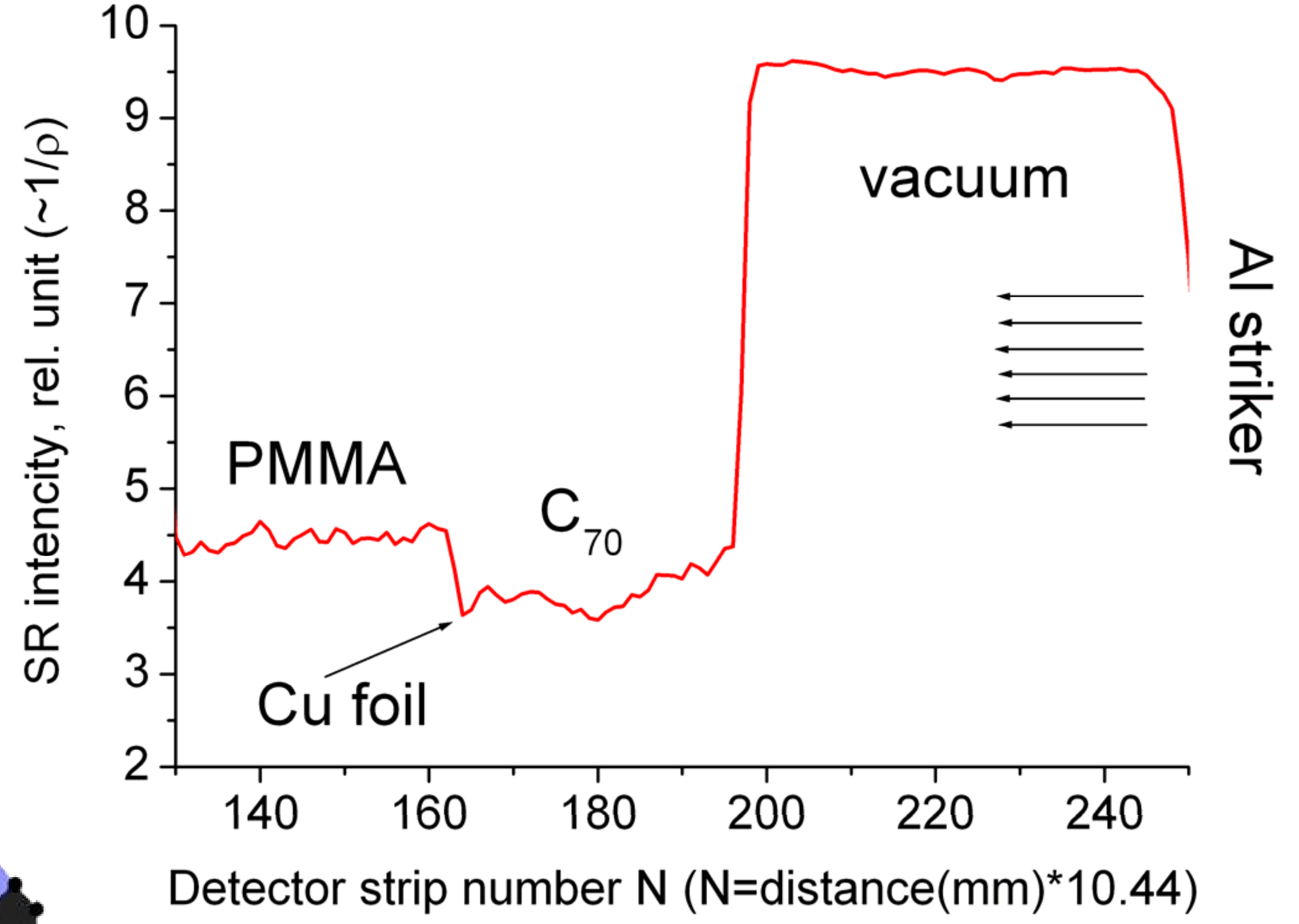
SR intensity 10^{17} photon/s×cm^2
SR beam divergence 10^{-5} rad.
SR bunch gap 250 ns
SR bunch duration 1 ns
SR spectral range 4 – 50 keV

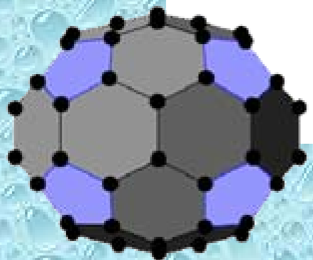
Experimental setup



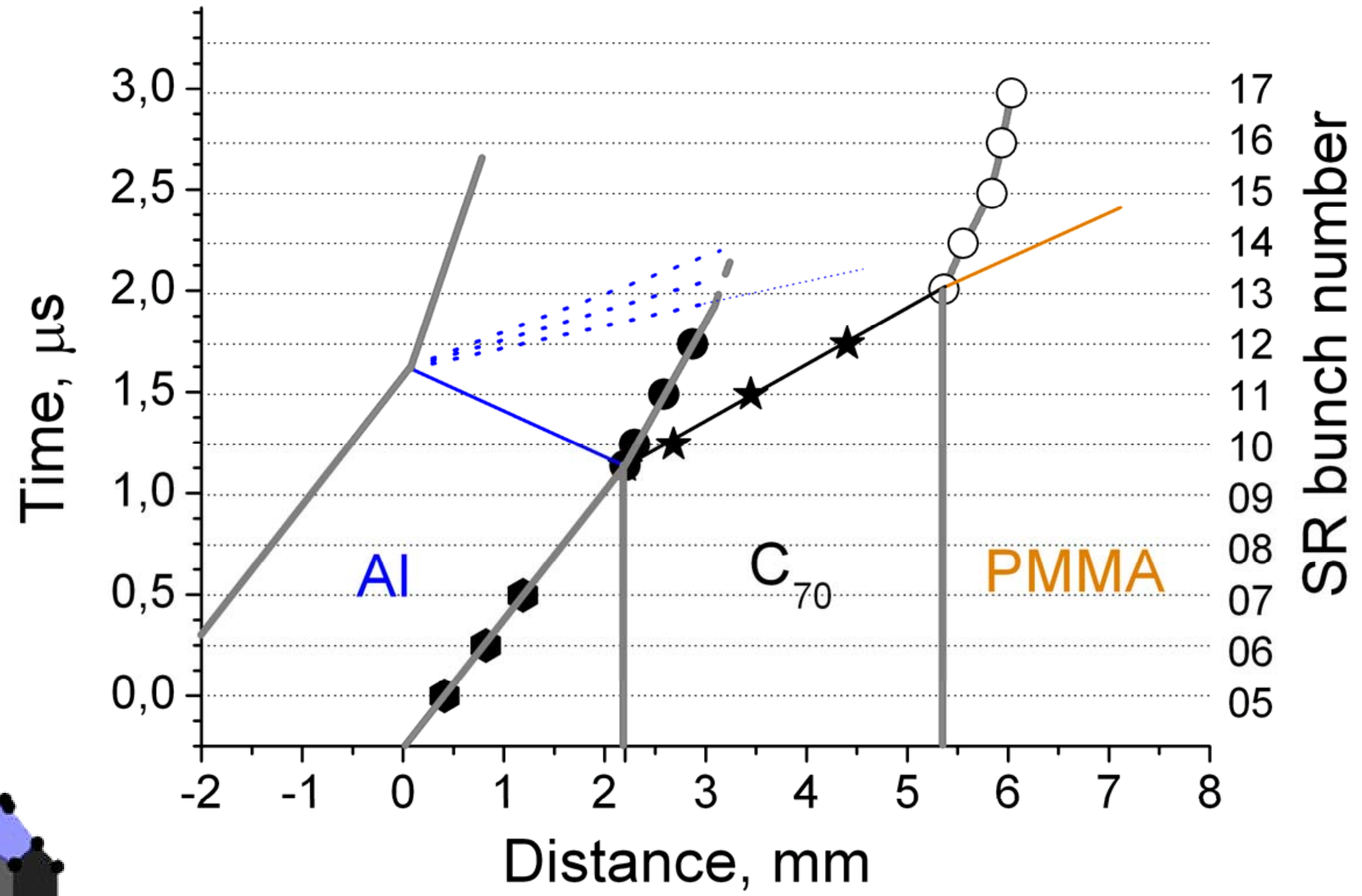
Fullerite C_{70}, 30% rombohedral + 70% hexagonal phase, ρ_0=1.663 g/cc
ρ_{00}=1.651 g/cc

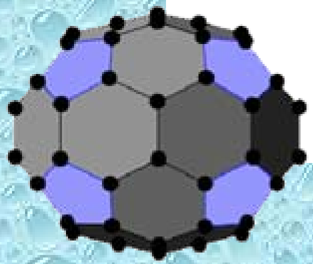
Starting experimental profile

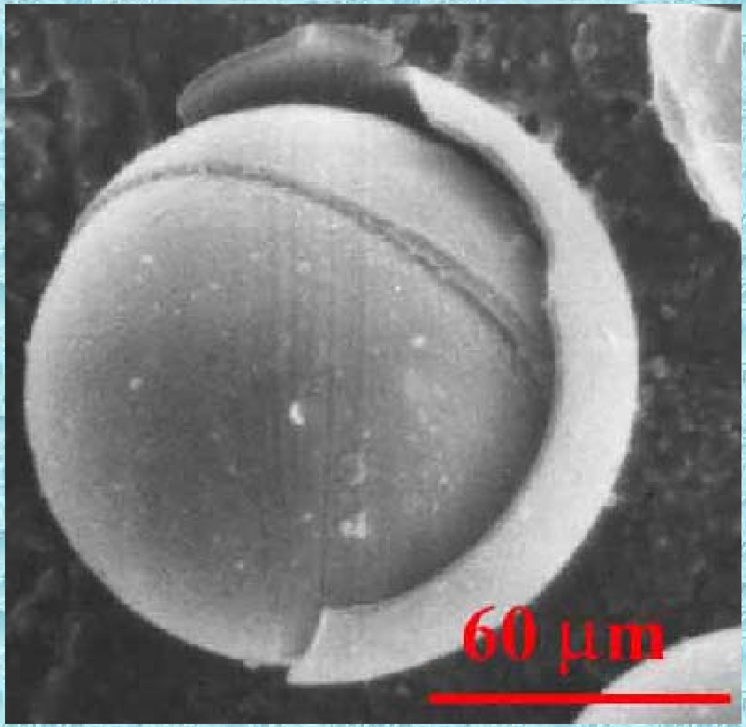


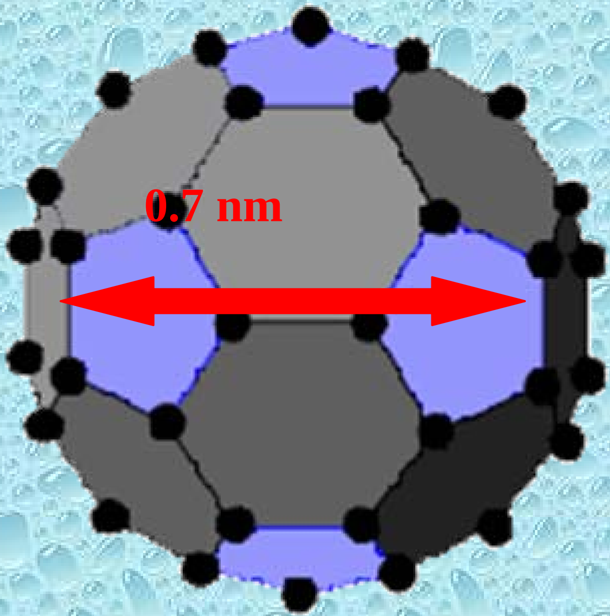


Experimental distance-time diagram









Glass microspheres are stable with respect to a pressure pulse up to ~ 0.25 GPa.
Fullerene molecules are stable with respect to a pressure pulse up to ~ 20 GPa. Bulk modulus of isolated C_{60} molecules is ~ 843 GPa*.

*R.S. Ruoff, Nature **360**, 663 (1991)].

Similar perspective properties:

1. Wide interval of densities is available
2. Two wave front fracture creation
3. Promising application for obtaining high energy density plasma

Differences:

Different types of porosities.

Payment for convinces in applications:

Two complicated phase diagram

Conclusions:

Developed approach is working for direct determination of material Hugoniot and investigation of shock wave front structure in porous media.

This approach may be displaced to PRIOR at FAIR

Thank you for your attention…