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I am a researcher in the astrophysical team of Keldysh Institute of Applied Mathematics (KIAM). My scientific interests are in computational hydrodynamics and magneto-hydrodynamics and its application for computational astrophysics. I am the author of Piecewise Parabolic Method on a Local Stencil (PPML), which has approved itself as one of the most precise finite-difference method for conservation laws. PPML was successfully applied to studying 3D supersonic turbulence in an astrophysical problem related to the formation of stars. I also implemented PPML solver to supernova explosion simulations, what allowed to construct a relevant asymmetric supernova model with nucleosynthesis computations.

Positions

Dec 2011 up to now	researcher in the astrophysical group of Keldysh Institute of Applied Mathematics (KIAM), Russia.
Sep 2010 – Nov 2011	PostDoc position at Laboratoire d'Annecy-le-Vieux de Physique Theorique (LAPTh), Université de Savoie, France.
Apr 2005 – Aug 2010	researcher in the astrophysical group of KIAM, Russia.
Apr 2001 – Mar 2005	Ph.D. student in the astrophysical group of KIAM, Russia

Degrees

2006 PhD, Mathematical Modelling & Numerical Methods − Keldysh Institute of Applied Mathematics. The thesis was titled “Numerical simulation of large scale convective instability in type Ia supernova explosions”.

2001 MSc, Theoretical Physics − Department of Theoretical Nuclear Physics of National Research Nuclear University "MEPhI". The diploma was titled “Bi-level system with two fermions in the external resonance electromagnetic field”.

Awards

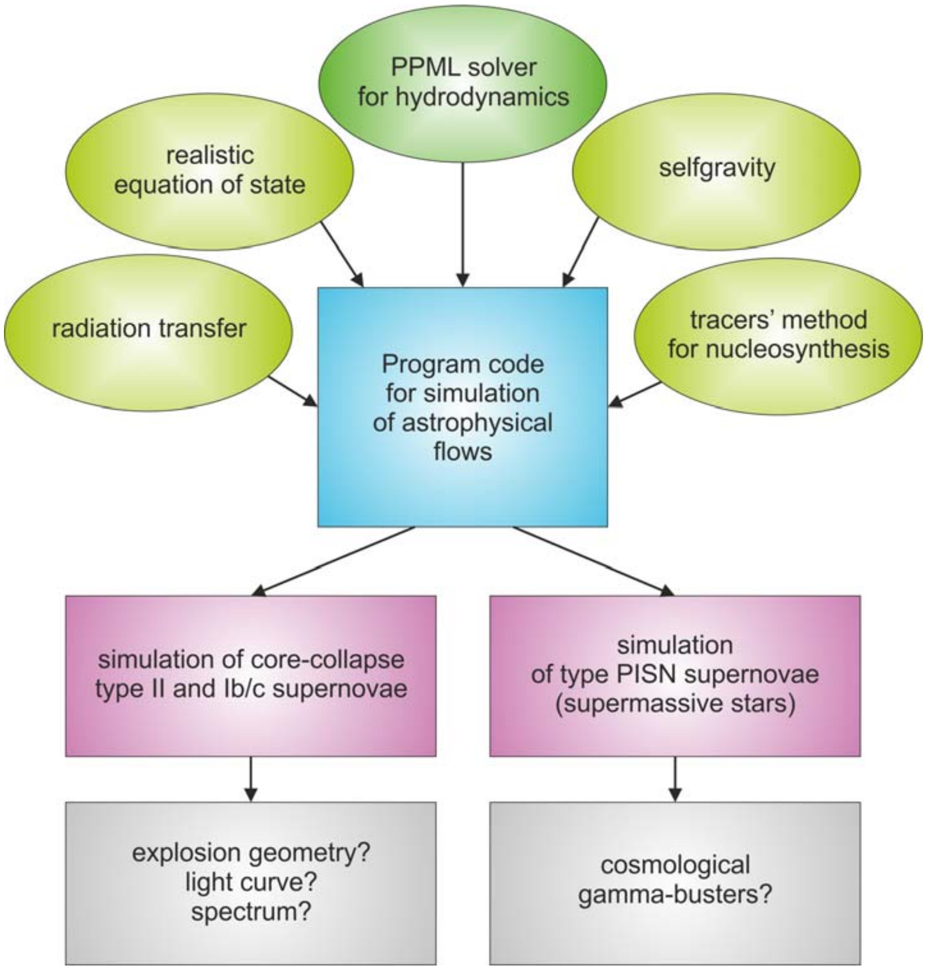
2012 Grant of Russian Foundation for Basic Research for young scientists with a Ph.D degree “My first grant”. Grant number: 12-02-31737mol_a.

2007 Grant of the president of Russia for the government support of young scientists. Grant number: MK-403.2007.2

Referees

1. **Pascal Chardonnet,** Professor at the University of Savoie, France chardon@lapp.in2p3.fr
2. **Valery Chechetkin**, Professor, Chief researcher at Keldysh Institute of Applied Mathematics, Russia chech@gin.keldysh.ru , chechetv@gmail.com
3. **Lev Titarchuk,** Professor at University of Ferrara, Italy titarchuk@fe.infn.it , lev@milkyway.gsfc.nasa.gov

The structure of my current research work is presented on the following diagram:



A. Development of the code for simulation of astrophysical flows. A new low-dissipative solver for numerical solution of Navier-Stokes equations is the core of this code (see M.V. Popov *Piecewise Parabolic Method on a Local Stencil in Cylindrical Coordinates for Fluid Dynamics Simulations*, Comput. Mathem. and Mathem. Phys., 2012, Vol. 52, Issue 8, pp.1186-1201). There is also the version of PPML solver for magneto-hydrodynamics. By development of the code we mean inclusion of additional program procedures and modifications which are necessary for realistic supernovae simulation, that are:

- modification of PPML for the equation of state which describes the matter under the extreme conditions of stellar cores. The current version of PPML works with the ideal gas;
- selfgravity computing in the course of development of hydrodynamic flows using an effective method for solution of Poisson equation for gravity potential;
- considering the heating of the matter of the ejected supernova's envelope due to the radiation;
- implementation of tracers' method for explosive nucleosynthesis computations.

The developing code will be used for numerical simulation of:

B. explosions of massive stars of the generation I in the local universe (type II and Ib/c supernovae). The geometry of the explosions will be studied for the different parameters of a progenitor star; in particular the influence of rotation on formation of jet-like structures will be studied. The yield of chemical elements will allow to estimate the presence of spectral lines and to compare with observations. The computation of the produced radioactive Ni^{56} will allow to estimate the light curve of a supernova. We expect to confirm the theoretical link between type Ib/c supernovae and local gamma-busters (GRBs).

C. explosions of supermassive (up to 1000 solar masses) stars of the generation III with low metallicity, which are on the cosmological distances from the Earth in the young universe. The numerical simulation should help to answer the question about the possibility to explain GRBs like the explosions of type PISN supernovae. This is a new scenario suggested during the international collaboration between Keldysh Institute of Applied Mathematic and Laboratoire d'Annecy-le-Vieux de Physique Theorique (LAPTH), Universite de Savoie, France (see P. Chardonnet, V.M. Chechetkin and L. Titarchuk, Astrophysics and Space Science, vol. 325, p. 153, 2010). This scenario avoids the problem of compactness and excites the great interest during discussions on the conferences.

The achievements and the current basement:

A. I created the code for hydrodynamic simulations – the PPML solver. A series of standard tests were performed: the Rayleign-Taylor instability in the single-mode and the multi-modes regimes, instability of Richtmyer-Meshkov, propagation of explosive shocks, implosion, the decay of contact discontinuities etc. Below we show just a single test – a bow shock, which is created in front of a dense object by supersonic flow (see fig. 1). PPML solver showed unique precision of the result with ideal symmetry conservation for the case of symmetrical initial data. This result was not reproduced by any other state-of-the-art modern code (see the discussion following the link: http://www.astro.virginia.edu/VITA/ATHENA/bow-shock.html). The comparison of the results of test computations obtained by the foreign analogs (Athena code, CASTRO code) showed superiority of PPML solver.

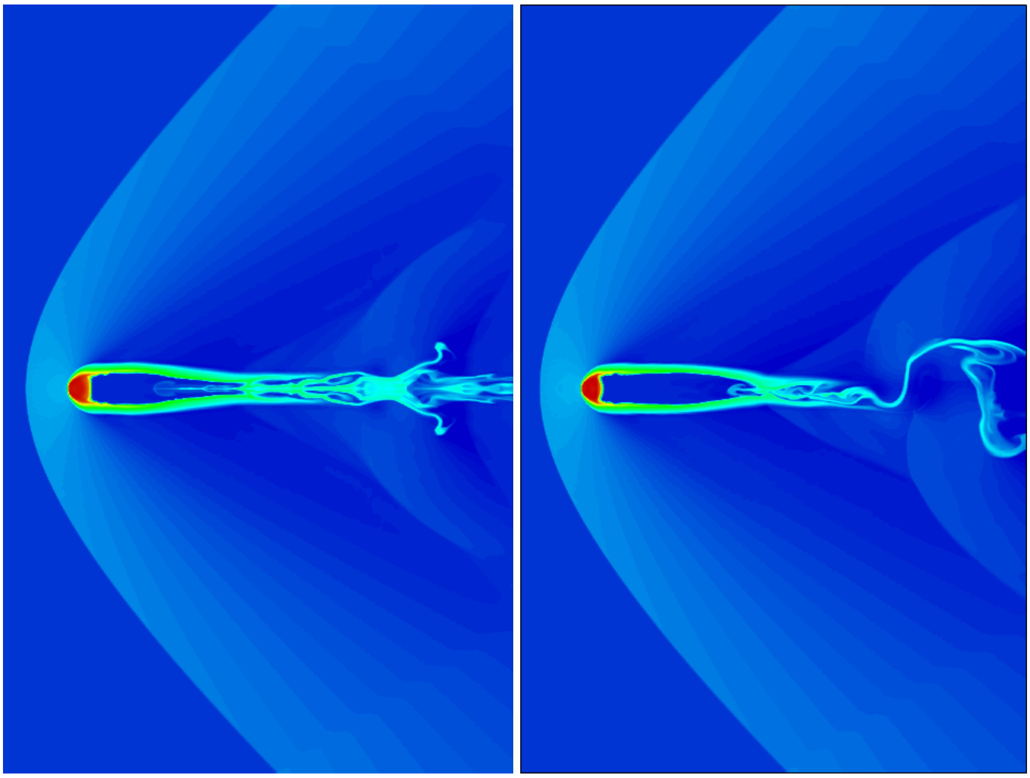


Fig. 1 Bow shock created in front of a dense object by supersonic flow. The fully symmetrical solution is shown on the left picture. It was obtained by the PPML solver on the symmetrical initial data. The solution which is on the right picture was obtained when the perturbations of order $\sim 10^{-15}$ (!) were introduced to the initial velocity field. This is on the edge of accuracy of real*8 floating point numbers. Such a small perturbations completely change the picture of the flow.

B. Using the PPML solver I created a hydrodynamic model of explosion of a stellar oxygen core of 100 solar masses in cylindrical geometry. The grid was 1600×1600 (the supercomputer of JSCC RAS was used). The explosion energy $E = 5.0 \times 10^{52}$ ergs was inserted into the central region of the star with small asymmetry, which represents the rotation. As an example, the structure of the flow for the moment of 19 sec is presented on fig. 2. As you can see, the PPML solver reproduces the small structures and the shocks with good quality. It was obtained the splitting of the forward shock, and the reverse shock, which was reflected from the center. Also the convective zone was discovered.

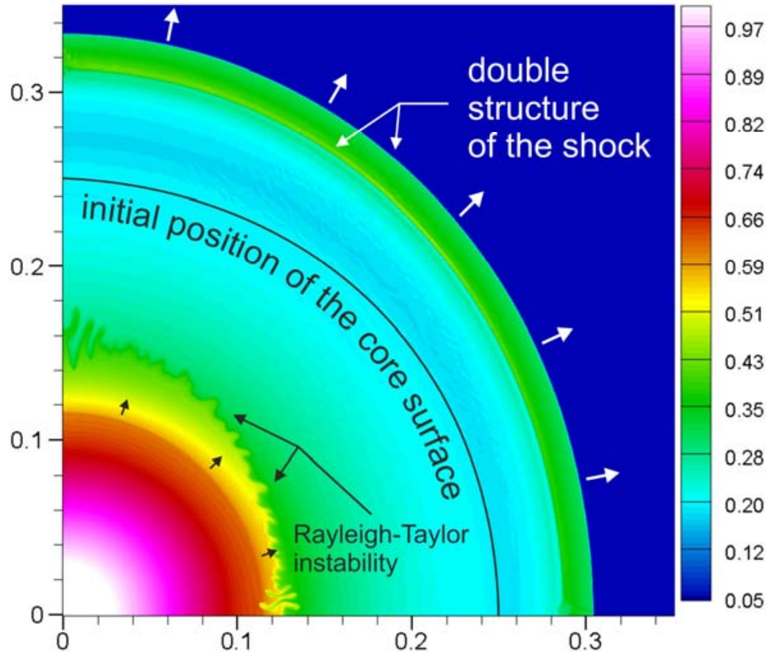


Fig. 2. Explosion of oxygen stellar core of 100 solar masses. The color represents temperature in the units of $T_c = 2.36 \times 10^9$ K, coordinates are in solar radiuses.

C. For nucleosynthesis computations the tracers' method was implemented. Tracers are the virtual particles which are passively advected by the flow without any coupling with it via gravity or inertia. The set of equations for nuclear abundances is solved here using the temperature and density history recorded along the tracers' path.

The nucleosynthesis in the explosive burning in the 25 solar masses stellar core was computed. The resulting distribution of the main isotopes is presented on fig. 3. A layer structure in the isotopes' distribution with the bubble of radioactive nickel was obtained. The nickel bubble propagates along the rotational axis of the star and locks the radiation inside itself while moving in the dense and opaque surrounding matter. The important result – the obtained distribution of the light elements (carbon, oxygen, neon). They form torus-like structure which is expanding along the equatorial plane of the star. The obtained geometry and chemical composition is consistent with theoretically predicted shock breakout phenomenon and is indirectly supported by some supernovae observations, i.e. by spectra and light polarization analysis of SN 2008D. This makes the used within the developing program code for supernovae simulation approaches and methods relevant and successful.

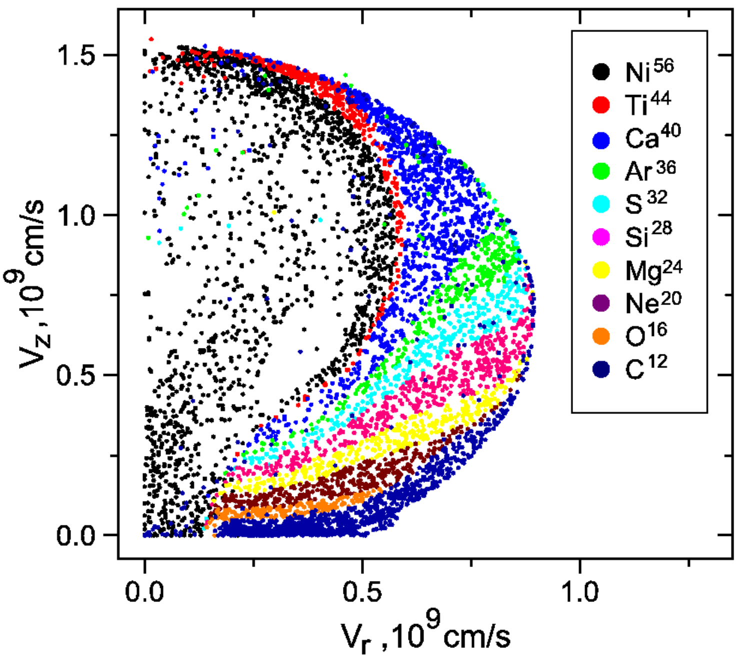


Fig. 3. The distribution of main chemical elements on the velocity plane in the supernova model.

Quasi-gasdynamic approach for numerical solution of magnetohydrodynamic equations

I also work on a new approach for numerical modelling of compressible liquids and gas flows based on the Quasi-Gasdynamic (QGD) equations. QGD equations are closely related with the Navier-Stokes equations and can be regarded as the NS system except for additional dissipative terms. These additional terms are the second-order space derivatives in a factor of a small parameter that has the dimension of time. These terms bring an additional non-negative entropy production that proves their dissipative character and contribute to the stability of the numerical solution. Simplicity of numerical realization and uniformity of the algorithm provides simple realization on parallel computers. The disadvantage of QGD approach is that this is a first-order scheme and it requires more detailed computational grid to obtain the quality of a solution comparative to high-order schemes, such as PPML. Still the method is robust and requires no additional monotonization procedures, e.g. limiting functions, what is very nice property especially for magnetohydrodynamic simulations.

Below I present some 3D MHD tests, obtained by QGD-code on the grid $120 \times 120 \times 120$.

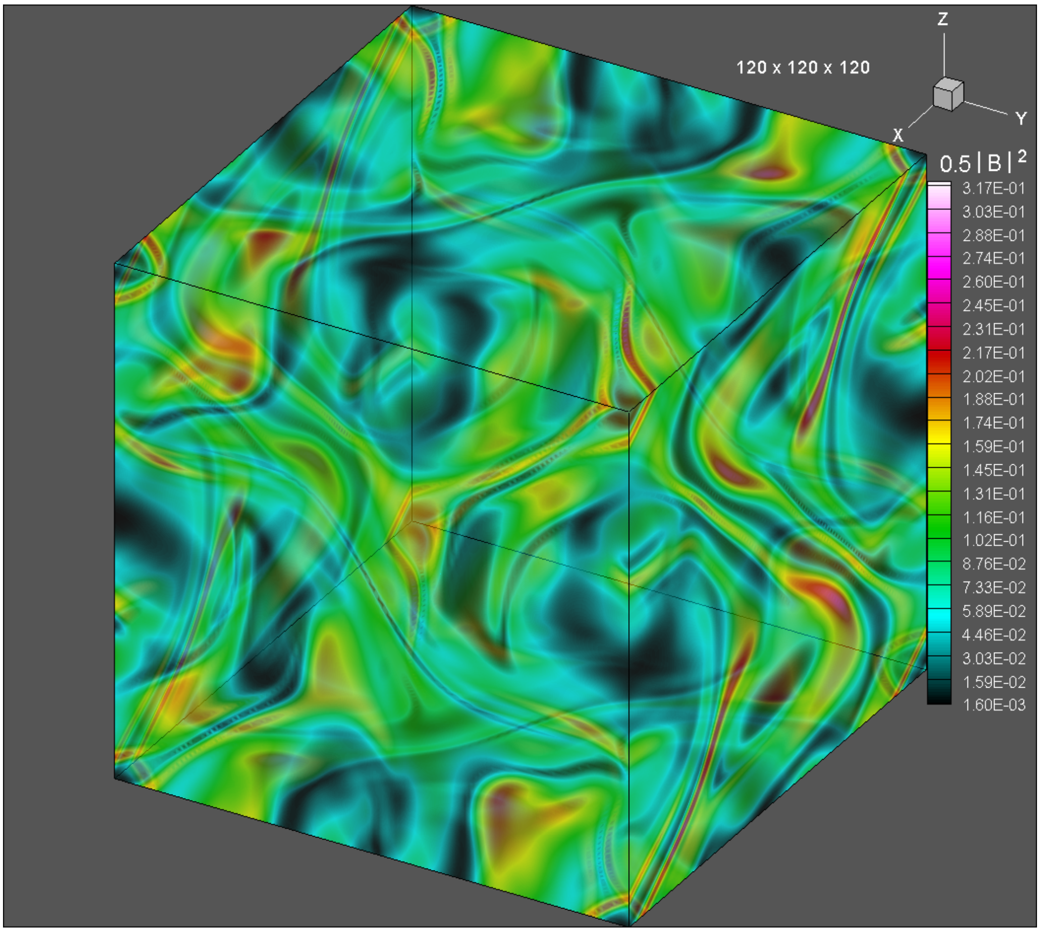


Fig. 4. Orszag-Tang vortex in full 3D case, $t = 0.5$ **s.**

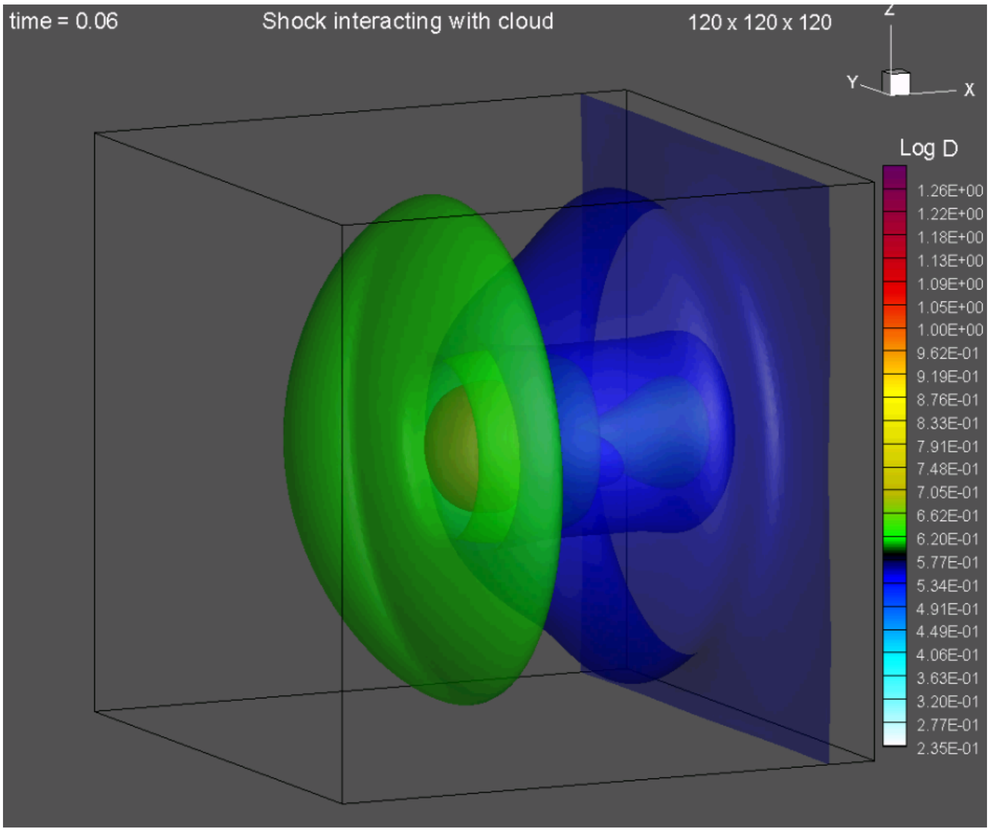


Fig. 5. Interaction of a shock wave with a cloud.

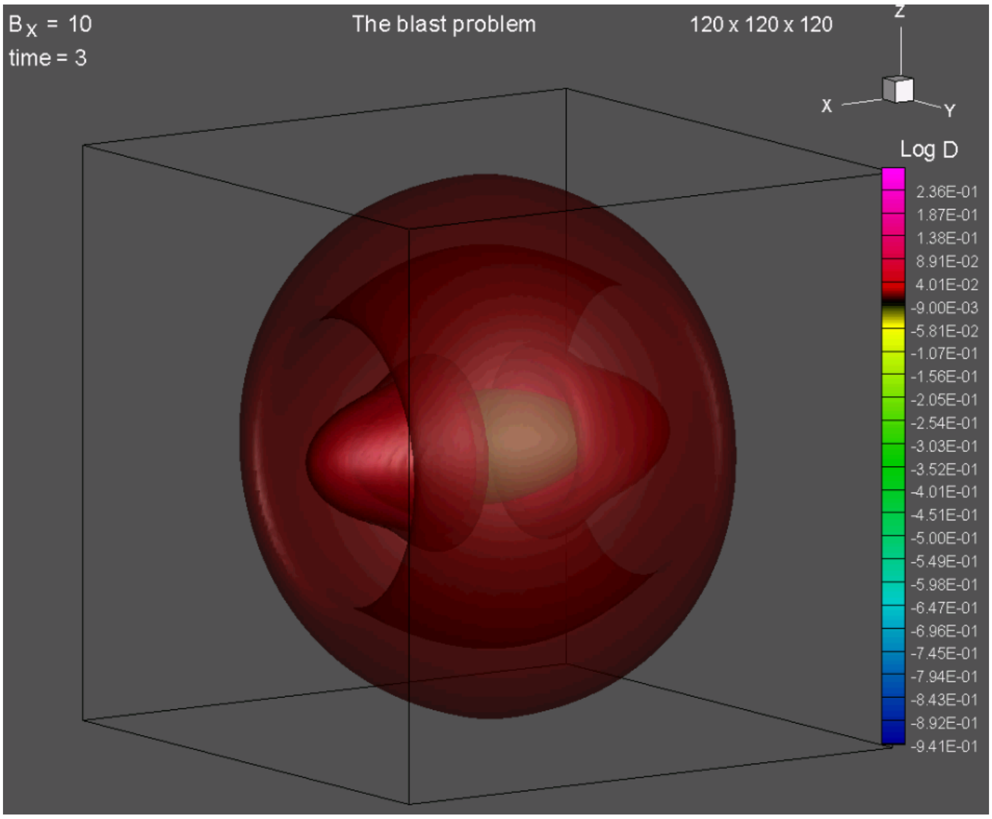


Fig. 6. A blast wave propagation through magnetized medium.

Publications

Refereed journals

1. M.V. Popov *Piecewise Parabolic Method on a Local Stencil in Cylindrical Coordinates for Fluid Dynamics Simulations*, Comput. Mathem. and Mathem. Phys., 2012, Vol. 52, Issue 8, pp.1186-1201.

2. V.G. Niziev, A.V. Koldoba, F.Kh. Mirzade, V.Ya. Panchenko, Y.A. Poveschenko, M.V. Popov, *Numerical Modeling of Laser Sintering of Two-Component Powder Mixtures*, Mathematical Models and Computer Simulations, 2011, Vol. 3, No. 6, pp. 723-731.

3. S.D. Ustyugov, M.V. Popov, A.G. Kritsuk, M.L. Norman *Piecewise Parabolic Method on a Local Stencil for Magnetized Supersonic Turbulence Simulation,* J. of Comp. Phys., 228 (2009) 7614-7633.

4. M.V. Popov, S.D. Ustyugov *Piecewise Parabolic Method on Local Stencil for Ideal Magneto-hydrodynamics*, Comput. Mathem. and Mathem. Phys., 2008, Vol. 48, Issue 3, pp.477-499.

5. M.V. Popov, S.D. Ustyugov *Piecewise Parabolic Method on Local Stencil for Gasdynamic Simulations*, Comput. Mathem. and Mathem. Phys., 2007, Vol. 47, Issue 12, pp.1970-1989.

6. V. Bychkov, M.V. Popov, A.M. Oparin, L. Stenflo, V.M. Chechetkin *Dynamics of Bubbles in Supernovae and Turbulent Vortices*, Astron. Rep., 2006, Vol. 50, No. 4, pp. 298–311.

7. M.V. Popov, S.D. Ustyugov, V.M. Chechetkin *Boundary Conditions for Simulations of the Thermal Outburst of a Type Ia Supernova*, Astron. Rep., 2005, Vol. 49, No. 6, pp. 450-458.

8. M.V. Popov, S.D. Ustyugov, V.M. Chechetkin *Development of the Geometric Structure of the Thermonuclear-Deflagration Front in Type Ia Supernovae*, Astron. Rep., 2004, Vol. 48, No. 11, pp. 921–933.

To be published in refereed journals

1. M.V. Popov, T.G. Elizarova, S.D. Ustyugov Quasi-Gasdynamic Approach for Numerical Solution of Magnetohydrodynamic Equations, Computers & Fluids J., submitted.

2. M.V. Popov, A.A. Filina, A.A. Baranov, P. Chardonnet, V.M. Chechetkin, *Aspherical Nucleosynthesis in the 25 Solar Mass Core-collapse Supernova Using the Tracer Particles Method*, Astrophys. J. Suppl. Ser., in preparation.

3. A.A. Baranov, P. Chardonnet, V.M. Chechetkin, A.A. Filina, M.V. Popov Population III stars: the Renaissance in Astrophysics, Astrophys. J. Suppl. Ser., in preparation

Conference Proceedings

1. V.M. Chechetkin, A.A. Baranov, M.V.Popov, A.Yu. Lugovsky *Supernovae explosions theory and compact remnant of SN 1987A*, The XII-th G. Gamow's Odessa Astronomical Summer Conference-School 20-26 August, 2012, Odessa, Ukraine; Odessa Astronomical Publications 2012, vol. 25/2.

2. A.A. Baranov, P. Chardonnet, V.M. Chechetkin, A.A. Filina, M.V.Popov *Application of code based on piecewise parabolic method on a local stencil (PPML) in a supernova explosion model*, in workshop proceedings ”From nuclei to white dwarfs and neutron stars”, Les Houches, France, April 3-8 2011.

3. A.A. Baranov, P. Chardonnet, V.M. Chechetkin, A.A. Filina, M.V.Popov *Pair-instability as a possible explanation of Gamma-Ray Bursts*, in workshop proceedings ”From nuclei to white dwarfs and neutron stars”, Les Houches, France, April 3-8 2011.

4. V.M. Chechetkin, M.V.Popov *Large-scale convection as a key process in supernovae explosions*, in workshop proceedings ”From nuclei to white dwarfs and neutron stars”, Les Houches, France, April 3-8 2011.

5. A.A. Filina, V.M. Chechetkin, M.V. Popov, *The distribution of chemical elements in thermonuclear burning in supernovae explosions*, in ”Scientific session of MEPhI-2012. Talks’ abstracts. In 3 volumes. Vol. 2: Fundamental Scientific Problems. Strategic IT technologies.” 2012, 388 pages [in russian].

6. V.G. Niziev, A.V. Koldoba, F.Kh. Mirzade, V.Ya. Panchenko, Yu.A. Poveschenko, M.V. Popov *Numerical modeling of sintering of two-component metal powders with laser beams*, Proceedings of SPIE - The International Society for Optical Engineering, Vol. 7994, 2011, Article number 79941W (International Conference on Lasers, Applications and Technologies, Kazan, 23 - 26 Aug. 2010).

7. M.V. Popov, S.D. Ustyugov *Piecewise Parabolic Method on a Local Stencil for Hyperbolic Conservation Laws*, Proc. of the 12th Int. Conf. on Hyperbolic Problems, University of Maryland, College Park, June 9-13 2008, Vol. 67.2, pp. 869-878 (2009).

8. M.V. Popov, S.D. Ustyugov *Piecewise Parabolic Method on a Local Stencil for Gas Dynamics and MHD*, AIP Conf. Proc., 2008, Vol. 1048, pp. 436-439.

9. V.M. Chechetkin, I.V. Baikov, M.V. Popov, V. Bychkov, L. Stenflo *Dynamics of Supernova Explosion*, AIP Conf. Proc., January 3, 2008 Vol. 966, pp. 117-122 RELATIVISTIC ASTROPHYSICS: 4th Italian-Sino Workshop.

10. V.M. Chechetkin, M.V. Popov, S.D. Ustyugov *Mechanisms of Supernovae Explosions*, Proc. of "Astrophysics and Cosmology after Gamow - Theory and Observations" (Odessa, August 8-14, 2004). Editors: G. Bisnovaty-Kogan, S. Silich, E. Terlevich, R. Terlevich, A. Zhuk. Cambridge Scientific Publishers, Cambridge (2006).

11. M.V. Popov *Convective Instability in Type Ia Supernova Explosion Model*, Gravitation and Cosmology, 2005, vol. 11, No.1-2 (41-42), pp.177-182, Proceedings of the International Conference on Cosmoparticle Physics (Cosmion-2004).

12. M. V. Popov *Convective Instability in thermonuclear burning process in a degenerate core of a star*, Scientific session of Moscow State Engineering and Physics Institute, Collected papers, 2004, vol. 7, pp. 36-37 [in Russian].

13. V.M. Chechetkin, M.V. Popov, S.D. Ustyugov, *Numerical simulation of large-scale convective instability in type II supernovae explosion*, “Mathematical simulation: problems and results”, Moscow, publisher “Science”, 2003, pp. 95-122 [in Russian].

14. V.M. Chechetkin, M.V. Popov, S.D. Ustyugov, *Numerical simulation of large-scale convective instability in type II supernovae explosion*, Modern problems of Space mechanics and physics, editors: member of the Academy of Sciences V.S. Avduevsky and prof. A.V. Kolesnichenko, Moscow, publisher “Science”, 2003, pp. 489-512 [in Russian].

15. V.M. Chechetkin, M.V. Popov, S.D. Ustyugov, *Numerical simulation of large-scale convection in type II supernovae explosion*, Proceedings of the Third Sakharov Conference on Physics, editors: M.Vasil’eva, V. Zaikina, A. Semikhatova, publisher “World of Science”, 2003, pp. 271-279.

16. V.M. Chechetkin, M.V. Popov, S.D. Ustyugov *Numerical Simulation of Large-scale Convection in Type-II Supernovae Explosion*, Gurzadyan V.G., Ruffini R. (Eds.), “Fermi and Astrophysics”, 2002, Il Nuovo Cimento (Italy), vol. 117 B, N. 9-11, pp. 1027-1041.