Fourth Virtual Workshop on Numerical Modeling in MHD and Plasma Physics: Methods, Tools, and Outcomes

Virtual, October 12-14, 2021

BOOK OF ABSTRACTS

The conference poster

An explicit scheme for 3D multicomponent heat-conducting flow simulation

O.B. Feodoritova [1], V.T. Zhukov[1]

[1]Keldysh Institute of Applied Mathematics RAS

Email: feodor@kiam.ru, vic.zhukov@gmail.com

The scheme LINS (Local Iterations for Navier-Stokes equations) is represented for the time integration of the multicomponent heat-conducting gas equations. These equations take into account the phenomena of multicomponent diffusion and heat transfer. The governing equation system is discretized by finite volume approach on three-dimensional unstructured grids. According to the algorithm, the computation of a single time step is split into the sequence of hyperbolic and parabolic stages. The hyperbolic subsystem is computed using the modified Godunov-type scheme [1]. The parabolic subsystem on diffusion stage is based on the explicit iterative Chebyshev scheme, which is algorithmically simple and does not involve tuning parameters [2].The diffusion stage addresses dissipative fluxes (viscosity, multicomponent diffusion and thermal conductivity). The number of the iterations is determined by the convective time step and by the upper bound for the difference diffusion operator. The resulting scheme ensures the fulfillment of the conservation laws at the discrete level, and its structure is well suited for efficient parallelization. The scheme is implemented within the NOISEtte aerodynamic code framework [3].

References

1. Zhukov V.T., Novikova N.D., Feodoritova O.B. An approach to time integration of the Navier–Stokes equations. Comp. Mathematics and Math. Physics. 2020. Vol. 60. № 2. P. 272-285
2. V E Borisov and Yu G Rykov. Modified Godunov Method for Multicomponent Flow Simulation. J. Phys.: Conf. Ser. 1250 012006, 2019, doi:10.1088/1742-6596/1250/1/012006
3. http://caa.imamod.ru/index.php/research/noisette

A numerical method for conjugate heat-transfer problem in multicomponent flows

O.B. Feodoritova [1], V.T. Zhukov[1]

[1]Keldysh Institute of Applied Mathematics RAS

Email: feodor@kiam.ru, vic.zhukov@gmail.com

We develop the numerical model of thermal interaction of gas flow with a solid body. The approach is based on CFD simulation in which the heat transfer in fluid domain and heat diffusion in the solid are fully coupled. This is known as the conjugate heat transfer (CHT) problem. The explorations are carried out for the problem of supersonic flows (fluid domain) over a finite thickness flat plate (solid domain). In the fluid domain, the flow is modeled taking into account the phenomena of multicomponent diffusion and heat transfer. In a solid domain, the energy equation is the traditional heat-conduction equation. According to the approach [1], the computation of a single time step is split into the sequence of hyperbolic and parabolic stages. Hence the energy equation for solid and fluid domains is the same must to be solved as a single equation using the explicit-iteration scheme LINS [1]. At the fluid-solid interface the matching conditions are the continuity of the temperature and the continuity of the normal component of the heat flux. These conditions are natural for the single heat-conduction equation and there is no need their special treatment. The proposed method is implemented within the NOISEtte code framework [2].

References

1. Zhukov V.T., Novikova N.D., Feodoritova O.B. Comp. Math. & Math. Physics. 2020. 60(2) 272-285
2. http://caa.imamod.ru/index.php/research/noisette

Novel methodology to obtain solutions around magnetised stars

Shilpa Sarkar; Indranil Chattopadhyay; Kuldeep Singh
Aryabhatta Research Institute of Observational Sciences, Nainital, India
shilpa@aries.res.in, shilpa.sarkar30@gmail.com

We propose a general methodology to obtain transonic accretion solutions around stars having strong magnetic fields in the ideal magneto-hydrodynamic (MHD) regime. The strong magnetic field near the star, forces the matter to follow the magnetic field geometry. The magnetic field is assumed to be dipolar, and the matter is channelled along these field lines, from the accretion disc to the star's surface. The accretion solutions around these compact stars are transonic in nature. To obtain a solution, we need to first locate the sonic point/points, where the radial velocity gradient (dv/dr) has a 0/0 form. In the presence of dissipative processes, finding a sonic point is not trivial. Also, the hard surface of the star drives a surface shock, after which the accreted supersonic matter becomes subsonic and finally settles down onto the surface of the star. We utilise a particular property of gravity to simplify the task of obtaining a transonic accretion solution as well as preserve the inner boundary conditions. We remember that gravitational pull on any particle of unit mass by an object of mass M_*, depends on the value of M_* and the distance between the centre of gravities of these two masses. Utilising this property, we can conclude that if a star of mass M_* and radius r_*, is confined in a radius r_{in} ($< r_*$), then the gravitational force experienced at a point r (where $r > r_* > r_{in}$) would be exactly the same, irrespective of whether the radius of the star is r_* or r_{in}. The feature of r_{in} is that, matter achieves free-fall velocities, and therefore at this boundary, all the values of the flow variables are known. This method, in brief, directs us to obtain the projected transonic accretion solution (we call it the 'ghost solution'), which forms a shock near the star surface, by selecting a boundary which is located in a region smaller than the actual star surface. The new proposed methodology uses the property of gravity; that is, it behaves as if the mass is concentrated at the centre of the star. We regenerated a host of solutions in one-temperature regime, previously obtained in literature, thereby validating our proposed methodology. We then proceed to obtain solutions in two-temperature regime. Unfortunately, two-temperature solutions possess degeneracy, and this methodology is the only way out to constrain it. This methodology reduced the complexity of obtaining a general transonic solution around a star with a hard surface and allowed us to obtain an exact and proper picture of the systems.

Null collision Monte Carlo simulation model for particle-in-cell method *

I.S.Chernoshtanov[1], A.A.Efimova[1], A.A.Soloviev[2],V.A.Vshivkov[1]
[1]*Institute of Computational Mathematics and Mathematical Geophysics SB RAS*
[2]*Institute of Automation and Electrometry SB RAS*

The article discusses the original null collision approach for modeling collisions in plasma for particle-in-cell method. A distinctive feature of the method is the simulation of particle collisions without the use of trigonometric functions and calculation of pairwise collisions (as is done in classical papers), which significantly increases the speed of the developed algorithms. Experimental results are presented that are associated with different approaches to calculating the collision frequency and conservation of energy and momentum. The developed algorithms are used in other software systems for modeling particle motion in a magnetic field. Comparison of the results of system's operation in the presence of collisions and in their absence is made.

* This work was supported by the Russian Science Foundation, project 19-71-20026.

Turbulent vortex dynamo in the Earth's atmosphere and the emerging opportunity to affect tropical cyclogenesis

G. V. Levina
Space Research Institute RAS, Moscow, Russia
levina@iki.rssi.ru

Following the author's presentation and publication at the MHD2020, the proposed application of the turbulent vortex dynamo theory to diagnosis of tropical cyclogenesis in the Earth's atmosphere was discussed in a series of International meetings, including the Conference on Hurricanes and Tropical Meteorology. The obtained results are intended to contribute to a development of operational, i.e. real time, diagnosis of the beginning of tropical cyclogenesis based on GOES Imagery and supported by cloud-resolving numerical modeling [1].

Meanwhile, the interpretation of tropical cyclogenesis as an extreme threshold event in the helical atmospheric turbulence [1] allows us to recall the idea on impacting on a hurricane birth. This was investigated within the framework of the wide-ranging research program in the USSR in the late 1980s, see reviews [2,3].

It is proposed to discuss the emerging opportunity based on modern knowledge.

This research was supported by program "Monitoring" no. 01200200164. Post-processing of cloud-resolving simulation was supported in part by the U.S. National Science Foundation, Grant ATM-0733380.

1. Levina, G.V. (2021). Helical tropical cyclogenesis: detection of pre-depression large-scale vortex instability. The AMS 34th Conference on Hurricanes and Tropical Meteorology, USA, 10-14 May 2021 (virtual); Abstract 371535/16C.7.
2. Levina G.V., Moiseev S.S., and Rutkevich P.B. Hydrodynamic alpha-effect in a convective system. Nonlinear Instability, Chaos and Turbulence. Vol. 2. Adv. Fluid Mech. Series, Debnath L. and Riahi D. N. (Eds.), Southampton: WIT Press, 2000, pp. 111–162.
3. Levina G.V. (2018). On the path from the turbulent vortex dynamo theory to diagnosis of tropical cyclogenesis. *Open J. Fluid Dyn.* **8**, 86–114.

The collapse from molecular cloud to stellar density: moving geodesic meshes vs. unstructured tetrahedron meshes vs. nested grids

Igor Kulikov
Institute of Computational Mathematics and Mathematical Geophysics SB RAS,
Lavrentieva ave., 6, Novosibirsk, 630090 Russia
kulikov@ssd.sscc.ru

In paper presents the results of studying the collapse from a cold molecular cloud to stellar density by means grid methods. For numerical simulation of collapse was used three grid computational models: a model based on multilevel nested grids, a model based on moving geodesic grids, and a model based on unstructured tetrahedral grids. Due to computational experiments, it was shown that the collapse process is most adequately reproduced when using multilevel nested grids with sufficient spatial resolution. The details of comparison will be shown in details in talk and in proceedings paper.

The reported study was funded by RFBR and FWF according to the research project 19-51-14002 (RFBR) and I 4311 (FWF).

The Numerical Simulation of the Shock Detonation of White Dwarfs

Igor Kulikov[1], Igor Chernykh[1], Dmitry Karavaev[1], Alexander Tutukov[2]
[1]Institute of Computational Mathematics and Mathematical Geophysics SB RAS, Lavrentieva ave., 6, Novosibirsk, 630090 Russia
[2] Institute of Astronomy RAS, 48-th Pyatnitskaya Street, Moscow, Russia
kulikov@ssd.sscc.ru

Type Ia supernovae are not only the source of the elements of «life» but also the «standard candles» for measuring distance in the Universe. In this talk, we describe the results of numerical modeling of the shock detonation of a white dwarf and the subsequent explosion of a Type Ia supernova. By means of supercomputer modeling, it was found that the dynamics of shock detonation are determined by the explosion energy and the ignition point. A hydrodynamic model of white dwarfs was built taking into account the nuclear burning of carbon, closed by the stellar equation of state and supplemented by the Poisson equation for the gravity was used. The results of the study of scalability and energy efficiency are presented.

This work was supported by the Russian Science Foundation (project 18-11-00044).

A semi-implicit unstructured operator-difference scheme for three-dimensional self-gravitating flows

Ilya Kondratyev, Sergey Moiseenko
Space Research Institute RAS, Moscow, Russia
National Research Institute "Higher School of Economics", Moscow, Russia
mrkondratyev95@gmail.com, moiseenko@iki.rssi.ru

An implicit operator-difference approach has proven itself well in modelling of two-dimensional astrophysical MHD problems with self-gravity on unstructured triangular meshes in Lagrange variables. In the talk the results of a three-dimensional extension of the method are presented. Following the operator-difference approach, we construct cell-nodal and nodal analogues of differential operators in Cartesian coordinates, where the conjugacy properties are the same as for original ones. Using the difference operators, we develop an Eulerian semi-implicit gas-dynamical solver with self-gravity on a three-dimensional collocated unstructured tetrahedral mesh. In the solver, only acoustic waves are treated implicitly, resulting to the only elliptic equation for a pressure on each time-step. The conjugacy properties of derived difference operators allow us to construct symmetric sign-definite matrices for this elliptic equation as well as for Poisson equation for a gravitational potential. The stability condition of the proposed scheme is milder, than the usual Courant-Friedrichs-Lewy condition for explicit solvers, and depends only on the gas velocity. To obtain monotonic solution profiles, we use a Rusanov-type numerical dissipation, which depends also only on the velocity of the flow. We apply a usual linear flux reconstruction of explicit terms to improve an order of spatial approximation. Results of test problems' simulations of low and high Mach number flows are presented.

Solving anisotropic heat equations by exponential shift-and-invert Krylov subspace methods

M.A. Botchev[1,2], V.T. Zhukov[1]
[1]Keldysh Institute of Applied Mathematics, RAS, Moscow,
[2]Marchuk Institute of Computational Mathematics, RAS, Moscow
botchev@ya.ru, vic.zhukov@gmail.com

Performance of the shift-and-invert Krylov subspace (Krylov-SAI) exponential time-integration schemes [1] are tested for solving 3D heat equation with strong anisotropy. The schemes are implemented with residual-based stopping criterion [2]. At each Krylov iteration a linear system with a symmetric positive definite matrix has to be solved, which can be done by any suitable parallelizable inner iterative solver. In our tests the AGMG algebraic multigrid solver [3] is employed. Test cases with various boundary conditions are considered. Numerical experiments show a mesh-independent convergence of the schemes, i.e., the number of the outer Krylov subspace iterations stays constant as the mesh is refined. The number of inner algebraic mutligrid iterations grows only moderately with the mesh size. With just a single Krylov subspace process Krylov-SAI exponential schemes are shown to deliver a very accurate solution for a whole time interval. The schemes outperform local iteration schemes and implicit schemes based on linear iterative solvers [4].

This work is partially supported by the Russian Science Foundation (grant No. 19-11-00338).

References

1. Van den Eshof J., Hochbruck, M. Preconditioning Lanczos approximations to the matrix exponential // SIAM J. Sci. Comput., 2006, 27 (4), pp. 1438–1457.
2. Botchev M.A., Grimm V., Hochbruck M., Residual, restarting and Richardson iteration for the matrix exponential // SIAM J. Sci. Comput. 2013, 35 (3), pp. A1376–A1397.
3. Notay Y., AGMG software and documentation, http://agmg.eu.
4. Zhukov V. T. Explicit methods of numerical integration for parabolic equations // Mathematical Models and Computer Simulations. 2011, 3 (3), pp. 311-332.

Mixed characteristic discontinuous Galerkin approach for perfect gas dynamics modeling

[1]Gatsuk V.K., [2]Lukin V.V.
[1]Bauman Moscow State Technical University
[1,2]Keldysh Institute of Applied Mathematics
[1]vikanessi@yandex.ru
[2]vvlukin@gmail.com

The numerical method based on the discontinuous Galerkin (DG) approach for perfect inviscid compressible gas dynamics modelling is developed. The approximate Riemann solvers in combination with gas dynamics equations system characteristic properties are used to calculate the numerical fluxes on the cells interfaces and inside the cells. A number of approximate Riemann solvers are considered. The solution characteristic decomposition used in the similar to PPML way and leads to eliminating of Runge – Kutta time integration which is standart for DG methods. The developed algorithm is tested using problems with smooth and discontinuous solutions. Both one-dimensional and two-dimensional test problems are considered. The method provides at least second order of accuracy, delicate discontinuity resolution and ability to compute gas-dynamic instabilities with minimal artificial distortion. In most cases both in 1D and in 2D problems the method doesn't need any limiter to obtain monotone solution but in some cases a little does.

Hybrid model of stationary plasma thruster

M.B. Gavrikov[1], A. A. Taiurskii[1]
[1]Keldysh Institute of Applied Mathematics
mbgavrikov@yandex.ru, tayurskiy2001@mail.ru

Investigation of processes in stationary plasma thrusters (SPT) was started in 1970 by A.I. Morozov. For over 40 years, SPTs have been successfully used to correct the orbits of spacecraft. The analysis of the main processes in SPT – ionization of the using substance (xenon) in the anode region, acceleration of the formed xenon ions, scattering of electrons and ions on the side ceramic walls of the device – has not yet been brought to reasonable engineering calculation methods that make it possible to obtain the characteristics of the projected SPD devices with acceptable accuracy. The main question that needs to be answered is where does it come from and what is the nature of the electromagnetic field that accelerates the ions? In addition, the role of the inductive electromagnetic field generated by plasma currents and charges in the formation of the SPT thrust force is unclear. For a theoretical analysis of the processes in SPT, the report proposed a hybrid plasma model, according to which the dynamics of ions and neutrals obey kinetic equations, and electrons are considered in the hydrodynamic approximation. In this case, the inertia of the electrons is taken into account in full, and the plasma is considered to be quasi-neutral. The final complete system of SPT equations constitutes the content of the hybrid electromagnetic hydrodynamics (EMHD) plasma model [1]. At the discrete level, similar approaches were used to analyze the expansion of a plasma bunch and some other problems [2]. In the report, a simplified 1D2V model of SPT is analyzed, which results from the assumption that radial processes in SPT do not make a significant contribution to the acceleration of ions along the axis of the device; in particular, the radial motion of electrons, their scattering on the side walls of the device, and near-wall conductivity can be neglected. The numerical analysis of solutions of 1D2V equations based on the Particle-in-Cell method made it possible to obtain a preliminary picture of plasma processes in SPT, in particular, to calculate the thrust force of the engine, the magnitude of the acceleration of xenon ions and the distribution along the device axis of the electromagnetic field and the concentrations of xenon atoms and ions arising from ionization

1. M.B. Gavrikov. Dvukhzhidkostnaia elektromagnitnaia gidrodinamika. – M.: KRASAND, 2018. 584 s.
2. L. Vshivkova, G. Dudnikova, K. Vshivkov. Hybrid Numerical Model of Shock Waves in Collisionless Plasma // AIP Conf. Proc. **1773**, 110017 (2016).

Numerical study of the influence of plasma inhomogeneity with allowance for bremsstrahlung on the absorption of Alfven wave by dissipative plasma

A. A. Taiurskii
Keldysh Institute of Applied Mathematics
tayurskiy2001@mail.ru

A mathematical model for the absorption of an Alfvén wave in a dissipative plasma, caused by dissipative effects and bremsstrahlung of electrons, based on the equations of two-fluid electromagnetic hydrodynamics with full account of the inertia of electrons is investigated in the paper. The investigation is aimed at studying the possible mechanism of anomalous heating of the solar corona by Alfvén waves arising in the solar photosphere [1]. Earlier [2], when studying a homogeneous plasma, it was shown that an Alfvén wave penetrates into a dissipative plasma to a finite depth, and its parameters stabilize over time, reaching a quasi-steady regime. In the present work, the influence of spatial density nonuniformity on the absorption of the Alfvén wave is investigated. We assume that the dissipative plasma fills the half-space, on the left boundary of which the Alfvén wave runs. Further propagation of the wave is associated with its absorption, which is the subject of study. An implicit difference scheme is used for numerical research of plane flows of a two-fluid plasma. The main types of heterogeneity are investigated: top and bottom. By alternating inhomogeneities of the top and bottom type, any spatial inhomogeneity of the plasma in terms of density can be obtained. The dependences on the value of the top of the depth of penetration of the Alfvén wave into an inhomogeneous plasma and the maximum temperatures of electrons and ions are obtained. The study showed that an increase in the amplitude of the incident wave leads to an increase in the values of the maximum temperatures of electrons and ions, as well as an increase in the depth of penetration of the Alfvén wave into an inhomogeneous dissipative plasma.

1. Scott W. McIntosh, Bart Pe Pontien, Marts Carlsson, Viggo Hansteen, Paul Boerner & Marsel Goossens. Alfvenic waves with sufficient energy to power the quiet solar corona and fast solar wind // Nature, 2011, v.475, p.478-480.
2. M.B. Gavrikov, A.A. Taiurskii // Journal of Physics: Conference Series, 2017, 937, 012014.

On a simple verification test of codes for modelling of magnetohydrodynamic turbulence

Igor Kulikov, Igor Chernykh, Marina Boronina
Institute of Computational Mathematics and Mathematical Geophysics SB RAS,
Lavrentieva ave., 6, Novosibirsk, 630090 Russia
kulikov@ssd.sscc.ru

In the paper results for modelling of a characteristic pattern of the solar wind flow and its turbulent structure are presented. We use a gravitational magnetic hydrodynamic model, and for the model we have created an effective numerical method based on Godunov's method and piecewise parabolic reconstruction of the solution. We consider the evolution of the MHD turbulence of the supersonic gas flow, where random strong transversal velocity disturbances are set, the problem is considered in the vertical magnetic field. For the formation of a reference test of the supersonic MHD turbulence evolution a detailed analysis of the flow is carried out.

Influence of the rotation of colliding molecular clouds on the structure of the forming protostellar systems

Boris Rybakin[a,1], Valery Goryachev[b]
[a]Scientific Research Institute for System Analysis of the RAS, MSU, Moscow
[b]Math Department, Tver State Technical University, 170026, Russia
[1]rybakin@vip.niisi.ru

The rotation of molecular clouds (MC) during their collision with each other plays a decisive role in the formation of protostellar structures. The research carried out in this work makes it possible to improve the understanding of how the angular momentum of rotation is transferred at all stages and in different areas of colliding MC's. Interest in the study of MC collisions and their influence on the formation of new stars has arisen for a long time [1]. There are many works devoted to these processes.

It should be noted that in most works, collision problems are investigated without taking rotation into account [2]. This paper presents the results of direct and tangential collisions of two MC's, whose rotation axes are perpendicular to the collision line. It is shown that the main contribution to the formation of a superdense substance that appears in the contact zone is made by the kinetic energy of the impact. Allowance for rotation (in one direction or in opposite directions) has a significant impact on the radial and azimuthal formation of filaments and clumps compared to collision studies without rotation.

Complicated flow redistribution is revealed in swirling annular zones outside the central zone of counter gas flows. Taking the rotation of molecular clouds into account made it possible to reveal additional dissipative effects into MO fragmentation. The influence of MC rotation on the initiation of Nonlinear Thin Shell Instability and the Kelvin-Helmholtz instability is investigated. The simulation showed that the density of clumps reaches values that can lead to the prestellar conditions formation. MC rotation leads to a redistribution of the final mass of the arising clumps, the time of their formation, and the appearance of a corrugated structure in clouds core.

Acknowledgments
This work has been supported RFBR Grant 19-29-09070 mk.

Literature

1. A. Habe, K. Ohta. Gravitational Instability Induced by a Cloud-Cloud Collision. PASJ, 44, 1992, 203-226, (1992).
2. Rybakin B., Goryachev V. Shape morphing in molecular cloud-cloud collision affected by coherent instabilities. Computers & Fluids, (2020), v. 205, DOI: 10.1016/j.compfluid.2020.104549.

3D numerical simulation of ribbon electron beam bending by relativistic proton bunch

G. Dudnikova, V. Vshivkov
Institute of computational mathematics and mathematical geophysics
gdudnikova@gmail.com, vsh@ssd.sscc.ru, chernykh@parbz.sscc.ru

Nowadays experiments in the field of high-energy physics require increasing the intensity and brightness of charged particle beams and developing new methods for their diagnosis. One of the noninvasive methods for diagnosing the parameters of an intense bunch of charged particles is based on the use of a low-energy ribbon electron beam [1, 2]. This paper presents a numerical model of the interaction process of the testing electron beam and the proton bunch under study. The model used to solve the problem consists of the equations of motion of the electron beam under the action of an electromagnetic field created by the relativistic proton bunch. The beam is modeled by calculating of electron trajectories passing through the 3D computational domain. The dependence of the electron beam deflection on its energy, the angle of inclination to the direction of the proton bunch, the magnitude of the space charge and the velocity of the proton bunch is investigated. It is shown that the amplitude of the electron beam deflection is proportional to the charge and gamma factor of the proton bunch and inversely proportional to the energy of the electron beam.

References

1. P. Forck, "Minimal invasive beam profile monitors for high intense hadron beams", Proc. PAC 2010, Kyoto, Japan, 2010, pp.1261-1265.
2. A. Aleksandrov, S. Assadi, S. Cousineau, et al, "Feasibility study of using an electron beam for profile measurements in the SNS accumulator ring", Proc. PAC 2005, Knoxville, USA, 2005, pp. 2586-2588.

Thermodynamics of dense gas in radiative magnetised winds

Wladimir E. Banda-Barragán
Hamburger Sternwarte, Universität Hamburg, Gojenbergsweg 112, D-21029 Hamburg, Germany
wbanda@hs.uni-hamburg.de

I discuss the thermodynamical evolution of dense gas clouds embedded in magnetised winds. Using 3D magnetohydrodynamical simulations of radiative clouds interacting with hot flows, I show that: a) clouds develop filamentary morphologies, b) entrained gas retains some information on the initial cloud density distribution, c) strong radiative cooling can sustain high-density gas along the outflow, and d) magnetic fields offer extra stability in some models, depending on their strength and topology. The interplay between radiative heating and cooling ensures that warm and cold gas clumps coexist with hot gas in a multi-phase flow. At the end, I compare the dynamical and morphological properties of outflowing gas in my simulations to those of the atomic gas phases in observed galactic winds.

Excitation of profiled plasma wakes by a couple of co-propagating laser pulses as a method of generating high-power THz radiation

E.A.Berendeev[1], I.V.Timofeev[2], E.P.Volchok[2], V.V. Annenkov[2]
[1] Institute of Computational Mathematics and Mathematical Geophysics SB RAS
[2]Budker Institute of Nuclear Physics SB RAS
evgeny.berendeev@gmail.com

It has been recently proposed to generate high-power terahertz radiation by the collision of two counter-propagating plasma wakes with mismatching profiles of electrostatic potential. The original idea has been based on the scheme in which these colliding wakefields in plasma are driven by femtosecond laser pulses focused either in different-size spots or in equal spots with the finite impact parameter. It has been shown that the efficiency of laser-to-THz energy conversion in such a scheme can reach maximum values 0.02%-0.03% only in the case when focal spot-sizes are comparable with the plasma skin-length. It has been also found that the produced radiation can have a narrow line width (1%-2%) only for the moderate laser strengths (a<0.7-0.8). It means that such a scheme cannot be efficiently applied to the most energetic petawatt-class laser systems in which such a low intensity requires large beam diameters. In this work, we study whether the efficiency of the proposed generating scheme can be kept high if we collide large-size plasma wakes with the small-scale nonuniform transverse structures. Using 2D3V PIC simulations in slab geometry and the method of virtual laser pulses allowing not to resolve laser wavelength, we show how to create such a profiled plasma wake by a couple of interfering co-propagating laser pulses traveling at a finite angle relative to each other.

The work is supported by RFBR and the Government of Novosibirsk region (grants 19-07-00446, 20-42-540008)

MHD Simulation of Magnetized Laboratory Jets

O.D. Toropina, G.S. Bisnovatyi-Kogan, S.G. Moiseenko

Space Research Institute
toropina@iki.rssi.ru

Astrophysical jets are observed on various astronomical scales: from active galaxy nuclei and quasars to compact objects in binary systems and young stellar objects. Until recently, the study of astrophysical jets was carried out using observations in the optical, radio and X-ray ranges and multidimensional numerical MHD simulations. Recently, methods of laboratory astrophysics have appeared. They allow to create of plasma jets using a lasers and study them in the laboratory.

We preset the results of MHD numerical simulations of the formation and development of magnetized jets considering external constant poloidal and toroidal magnetic fields. In each configuration a picture of the plasma flow, the distribution of the plasma density and energy, and the structure of the jet at different distances and at different are obtained. In the case of an external poloidal magnetic field, the matter forms a directional jet and can be observed on the opposite side of the chamber in the form of a clear spot or a ring structure, depending on the magnitude of the magnetic field. In the case of a toroidal magnetic field, in most of the studied configurations, the substance is also collimated into a directional jet and can be observed as a ring structure on the opposite side of the chamber. The size of the ring depends on the strength of the magnetic field. Using the derived similarity criteria, the numerical simulation results were compared with the jet parameters obtained in a laboratory experiment at the NEODIM facility at TsNIIMASH.

Effects of radiative energy losses on the structure of stellar wind interaction with interstellar medium

Anastasia Titova, Vladislav Izmodenov, Sergey Korolkov
Space Research Institute (IKI) Russian Academy of Sciences, Moscow, Russia
Lomonosov Moscow State University, Center for fundamental and applied mathematics, Moscow, Russia
National Research University Higher School of Economics
avtitova_1@edu.hse.ru

We present two-dimensional axisymmetric gas dynamic simulations of interaction between hypersonic stellar wind and interstellar medium that moves with respect to the star with supersonic speed with inclusion of radiative losses from optically thin plasma. The aim of this research is to explore the influence of radiative cooling on the size and global shapes of astrospheres.
It is demonstrated that the solution depends on five dimensionless parameters: γ (the adiabatic index), M_∞ (the Mach number in undisturbed interstellar medium), χ (the ratio between terminal speed and interstellar medium speed), as well as α and θ which are related to the energy losses; α is responsible for radiative cooling power, θ is interstellar medium temperature divided by 10^4 K.
Results show that radiative losses have a significant influence on the flow pattern. The gas cooling causes the increase of density and pressure which leads to the compression of the interaction region and changing the position of the astropause. We also explore the growth of Kelvin-Hemholtz instability appearing at tangential discontinuities with increasing of cooling power α.

Non-equilibrium Photoionization and Hydrodynamic Simulations of Starburst-driven Outflows

Ashkbiz Danehkar, M. S. Oey, and William J. Gray
Department of Astronomy, University of Michigan, 1085 S. University Ave,
Ann Arbor, MI 48109, USA
danehkar@umich.edu

Observations of starburst-driven galactic outflows in star-forming galaxies have revealed some complex thermal structures that are difficult to explain by adiabatic fluid models in photoionization equilibrium (PIE) and collisional ionization equilibrium (CIE). We therefore conduct hydrodynamic simulations of starburst-driven outflows, and calculate time-dependent non-equilibrium ionization (NEI) states and thermal profiles using the MAIHEM module for non-equilibrium atomic chemistry and radiative cooling functions in the adaptive mesh hydrodynamics code FLASH. Through extensive non-equilibrium photoionization calculations made with the NEI states produced by our hydrodynamic simulations, we predict the UV and optical line emission flux ratios for starburst-driven outflows in non-equilibrium conditions. Our hydrodynamic results demonstrate applications of non-equilibrium radiative cooling for H II regions in starburst galaxies that have been reported to contain strongly cooling galactic outflows.

Algorithms of motion in the particle-in-cell method

K.V. Vshivkov[1], L.V. Vshivkova[1], E.A. Efimova[1], E.S. Voropaeva[2], G.I. Dudnikova[1]
1. Institute of Computational Mathematics and Mathematical Geophysics SB RAS
2. Novosibirsk State University
kovsh@ssd.sscc.ru

This paper deals with new algorithms for particle motion that can be used to solve a wide range of problems in the physics of laboratory and space plasma using the particle-in-cell (PIC) method. Since the PIC method uses a large number of model particles, an economical algorithm to compute the velocities and coordinates of particles at a time step is important. In 1970 Boris proposed an algorithm that was economical in terms of the number of operations and have been widely used till our days. Our new scheme proposed to solve the equations of motion at a time step is economical and more accurate. In practical computations, the values of the electric and magnetic fields at the location of the particle are obtained by interpolation from the nodes of a computational grid. The study of the effect of interpolation on the running time of the algorithm showed that the interpolation time in three-dimensional calculations is an order of magnitude longer than the time of calculating the particle motion. In this work, the method to reduce the cost of field interpolation, which allows computations for long physical times, has been developed.

This work was supported by the budget project of ICM&MG SB RAS (project 0251-2021-0005) and the Russian Foundation for Basic Research, grant 18-29-21025-mk.

Parallel Algorithm for Calculating the Dynamics of the Electron Beam Current Distribution

Galina G. Lazareva[1]
RUDN University
lazareva-gg@rudn.ru

On the experimental stand Beam of Electrons for materials Test Applications (BETA) created in the INP SB RAS, the results of heating the tungsten plate by the action of a high-speed electron beam on it were obtained. We consider an extended dynamic model of current distribution when the surface of a tungsten sample is heated by an electronic beam pulse. The temperature in the sample, calculated from the two-phase Stefan problem, is needed to solve the electrodynamic equations. A special case of axial symmetry without taking into account electrical driving forces is considered. The current is considered as a possible source of rotation of the substance, which is observed in the experiment. A parallel version of the algorithm, implemented using OpenMP technology, is presented. The aim of the study is to simulate the erosion of the sample surface as a result of evaporation and penetration of heat flux into the material.

This work is supported by the Ministry of Science and Higher Education of the Russian Federation: agreement no. 075-03-2020-223/3 (FSSF-2020-0018).

Modelling of the interstellar dust distribution under the influence of the interstellar magnetic field.

E.A. Godenko[1,2,3,*], V.V. Izmodenov[2,3,1]

1. Ishlinsky Institute for Problems in Mechanics of RAS
2. Space Research Institute of RAS
3. Lomonosov Moscow State University, Moscow Center for Fundamental and Applied Mathematics

**eg24@yandex.ru*

Due to the relative motion of the Sun the interstellar dust (ISD) particles can penetrate into the heliosphere. For ISD we consider spherical grains and its chemical composition is astronomical silicates. Three main forces influence the ISD motion in the heliosphere and its surrounding: the solar gravitational force, the radiation pressure force and the electromagnetic force. The global goal of this work is to create a model of the ISD distribution in the heliosphere and, particularly, find regions with increased number density of ISD. To understand the locations of the ISD accumulations may be actual for the planning of future scientific space missions and also in the context of the astronomical observations, because dust grains absorb and scatter the light.

We use a kinetic approach for description of the ISD motion and distribution in the heliosphere and, correspondingly, calculate the ISD velocity distribution function inside the heliosphere. In our previous works we investigated the peculiarities of the ISD grains in the heliosphere [1] and the effects of velocity dispersion on these peculiarities [2]. Here we study the influence of the interstellar magnetic field on the ISD distribution in the outer heliosphere. For this purpose, we also have to calculate the electric charge of the interstellar dust particles, which depends mainly on the flux of plasma ions and electrons, secondary emitted electrons and photoelectrons. The structure of the interstellar magnetic field in the vicinity of heliopause creates the conditions for the effect of filtration: small ISD particles align along the lines of the interstellar magnetic field and that is why they don't penetrate into the heliosphere. For all sizes of the ISD particles, we determine the fraction of particles penetrating into the heliosphere. Due to this effect of filtration for small particles some regions of increased number density appear in the vicinity of heliopause. We show that for big particles, the interstellar magnetic field almost doesn't affect the ISD motion.

1. Mishchenko A.V., Godenko E.A., Izmodenov V.V., 2020, MNRAS, **491, p. 2808.**
2. Godenko E.A., Izmodenov V.V., 2021, Astronomy Letters, **47, 1, p. 50.**

Parallel Algorithm for Calculating the Dynamics of Tungsten Vapor Distribution

Anastasia G. Maksimova [1]
Galina G. Lazareva[2]
[1] Novosibirsk State University, Novosibirsk, Russian Federation

[2]RUDN University

maksimova@oapmg.sscc.ru
lazareva-gg@rudn.ru

We consider an extended dynamic model of tungsten vapor distribution when the surface of a tungsten sample is heated by an electronic beam pulse. The parameters of the model are taken from the experiments on the Beam of Electrons for materials Test Applications (BETA) stand. This stand was designed in the INP SB RAS. The temperature in the sample is calculated from the two-phase Stefan problem. The temperature on the surface of the sample is taken as a boundary condition for the system of gas dynamics equations. A case of axial symmetry is considered. A parallel version of the algorithm, implemented using OpenMP technology, is presented

This work is supported by the Ministry of Science and Higher Education of the Russian Federation: agreement no. 075-03-2020-223/3 (FSSF-2020-0018).

Mathematical modelling of beam dynamics in diamagnetic confinement regime of open trap

M.A. Boronina, I.G. Chernykh, G.I. Dudnikova, E.A. Genrikh, V.A. Vshivkov
Institute of Computational Mathematics and Mathematical Geophysics SB RAS,
Lavrentieva ave., 6, Novosibirsk, 630090 Russia
boronina@ssd.sscc.ru

The talk is devoted to the mathematical modelling of a beam injected into an open magnetic trap in the diamagnetic mode. The two-dimensional axially symmetric hybrid numerical model with the kinetic approximation for the ion component of the plasma and the MHD approximation for magnetized electrons is used. In the numerical experiments, the possibility of formation of the cavity in the magnetic field was shown. A detailed study of the evolution of the ion beam continuously injected into the trap is done, the dependencies on time, moment of injection and beam temperature are presented. The obtained results may be used for the data analysis of the laboratory experiments in open magnetic systems.

The computations were performed on Siberian Supercomputer Center cluster (ICM&MG SB RAS, Novosibirsk, Russia). The work is supported by Russian Science Foundation (project N 19-71-20026).

Numerical simulation of plasma flow acceleration modes

A.N. Kozlov [1,3], V.A. Bakhtin [1,3], K.M. Gutorov [2], N.S. Klimov [2], V.S. Konovalov [1], D.V. Kovalenko [2], S.O. Novikova [1,3], V.L. Podkovyrov [2], A.A. Taiurskii [1], R.V. Urlova [2], A.D. Yaroshevskaya [2]

[1] Keldysh Institute of Applied Mathematics, RAS, Moscow
[2] Institute for Innovation and Fusion Research, Troitsk, Moscow
[3] Lomonosov Moscow State University, Faculty of Mechanics and Mathematics
andrey-n-kozlov@mail.ru

Previously, the studies of the quasi-stationary plasma accelerators (QSPA) were carried out mainly within the framework of the program of the controlled thermonuclear fusion (see e.g. [1, 2]). At the same time, the QSPA are multifunctional installations with various applications. Experiments, which carried out at the Institute for Innovation and Fusion Research (see e.g. [3]), allow to determine the different characteristics of plasma flows, including velocity and concentration. Numerical modeling is carried out mainly at the Keldysh Institute of Applied Mathematics (see e.g. [4, 5]).

Two-dimensional axisymmetric plasma flows were calculated for various parameters of the problem and the geometry of the accelerating channel of the QSPA. The optimization of the channel geometry was carried out in order to obtain the stable plasma flows corresponding to the required integral characteristics.

This work was supported by the Russian Foundation for Basic Research (project No. 18-29-21007_мк).

1. Klimov N., Podkovyrov V., Zhitlukhin A., Kovalenko D., et al. Experimental study of PFCs erosion under ITER-like transient loads at plasma gun facility QSPA. // Journal of Nuclear Materials. 2009. V. 390-391. P. 721-726.
2. Kozlov A.N. The study of plasma flows in accelerators with thermonuclear parameters. // Plasma Physics and Controlled Fusion. 2017. V. 59, No. 11. 115004.
3. Klimov N.S., Kovalenko D.V., Podkovyrov V.L., Kochnev D.M., Yaroshevskaya A.D., Urlova R.V., Kozlov A.N., Konovalov V.S. Experimental study of integrated characteristics of plasma stream and discharge of a quasi-stationary high-current plasma accelerator with its own magnetic field. // Problems of Atomic Science and Technology. Series: Thermonuclear fusion. 2019. V. 42, No. 3. P. 52-63.
4. Kozlov A.N., Konovalov V.S. Numerical study of the ionization process and radiation transport in the channel of plasma accelerator. // Communications in Nonlinear Science and Numerical Simulation. 2017. V. 51. P. 169-179.
5. Kozlov A.N., Konovalov V.S., Klimov N.S., Kovalenko D.V., Podkovyrov V.L., Urlova R.V., Gutorov K.M. The study of radiation transport in a flow of ionizing helium in plasma accelerator. // Keldysh Institute of Applied Mathematics. Preprint No. 61, 2020.