University of Craiova

Department of Physics

International Workshop

Transport in Fusion Plasmas

TFP 2009

November 9 – 10, 2009, Craiova, Romania

Bilateral Cooperation

Romania - Wallonie , Bruxelles

ANCS Financial Support

Programme of the Workshop

Monday 9 November 2009

09:30 – 09:45 Get together of participants,
hand out of the programme, coffee

Session 1

Chair: Nicolae Pometescu

09:45 – 10:00 Welcome address
Radu Constantinescu
Dean of the Faculty of Physics of University of Craiova

10:00 – 10:50 **Boris Weyssow**
Université Libre de Bruxelles, and
EFDA-CSU, Garching bei München

Selected Topics in Fusion research performed under the European Fusion Development Agreement

10:50 - 11:40 **Sara Moradi**
Université Libre de Bruxelles

Charge dependence of impurity peaking factor

11:40 - 12:00 *Coffee break*

12:00 - 12:50 **Cristian Petrica Lungu –** National Institute for Lasers, Plasma and Radiation Physics, Magurele, Romania

Berylium based films coatings for fusion applications

12:50 - 13:30 **Sara Moradi**
Université Libre de Bruxelles

Modeling of plasma non-local transport using CTRW and fractional derivatives

13:30 – 15:00 *Lunch*

Session 2

Chair: Boris Weyssow

15:00 – 15:50 **Nicolae Pometescu -** University of Craiova, Department of Physics

Modelling random transition between two temperature profiles

15:50 – 16:40 **Iulian Petrisor -** University of Craiova, Department of Physics

The zonal flow in anisotropic weak turbulence

16:40 – 17:00 *Discussions and remarks*

17:00 - 19:00 *Visit Craiova*

19:30 – 21:30 *Dinner*

Tuesday 10 November 2009

Session 3

Chair: Emilia Petrisor

09:00 – 09:40 **Dana Constantinescu**
University of Craiova, Department of Applied Mathematics

Stochastic and regular dynamics in some models proposed for the study of the sawtooth phenomena in tokamaks

09:40 – 10:20 **Boris Weyssow**
Université Libre de Bruxelles and EFDA-CSU, Garching bei München

On some applications of the Smoothed Particle Hydrodynamics method to flows driven by magnetic fields

10:20 – 11:00 **Nicolae Pometescu**
University of Craiova
Department of Physics

Dispersion equation for ITG instability in plasma with ICRH

11:00 – 11:30 *Coffee Break*

Session 4

Chair: Dana Constantinescu

11:30 – 12:10 **Emilia Petrisor**
Polytechnic University of Timisoara,
Department of Mathematics

A strong obstruction to the existence of invariant tori in Hamiltonian systems

12:10 – 12:50 **Petre Bazavan**
University of Craiova,
Department of Mathematics

On variable time-steping Runge-Kutta methods and approximation of attractors

12:50 – 13:30 **Marian Negrea**
University of Craiova,
Department of Physics

Aspects of the Diffusion in Tokamak Plasma

13:30 – 15:00 *Lunch*

15:00 – 15:40 **Calin Vlad Atanasiu**
National Institute for Laser, Plasma and Radiation Physics. Bucharest-Magurele

Numerical methods for kinetic equations

15:40 – 16:20 **Afrodita Boldea**
West University of Timisoara
Costin Boldea - University of Craiova

Applications of Symmetry Methods for Hasegawa - Mima equation

16:20 – 17:00 *Remarks at closing of the Workshop*

List of participants

- Atanasiu Calin Vlad – NILPRP Bucharest Magurele
- Bazavan Petre – University of Craiova
- Boldea Afrodita – West University of Timisoara
- Boldea Costin – University of Craiova
- Coshulski Mirel – University of Craiova
- Constantinescu Dana – University of Craiova
- Constantinescu Radu – University of Craiova
- Lungu Ana – NILPRP Bucharest Magurele
- Lungu Cristian Petrica – NILPRP Bucharest
- Moradi Sara - Université Libre de Bruxelles
- Negrea Marian – University of Craiova
- Osiac Mariana - University of Craiova
- Petrisor Emilia - Polytechnic University of Timisoara
- Petrisor Iulian – University of Craiova
- Pometescu Nicolae – University of Craiova
- Vanhaelen Quentin - Université Libre de Bruxelles
- Weyssow Boris - Université Libre de Bruxelles

Abstracts of the talks

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Selected Topics in Fusion research performed under EFDA

In 1999, the **European Fusion Development Agreement** (EFDA) was created to provide a framework between European fusion research institutions and the European Commission to strengthen their coordination and collaboration, and to participate in collective activities.
Between 1999 and 2007 EFDA was responsible for the exploitation of the Joint European Torus, the coordination

and support of fusion-related research & development activities carried out by the Associations and by European Industry and coordination of the European contribution to large scale international collaborations, such as the ITER-project.

On some applications of the Smoothed Particle Hydrodynamics method to flows driven by magnetic fields

B. Weyssow[1,2], Q. Vanhaelen[1]

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Abstract
The SPH method consists in a discretization of hydrodynamical equations leading to a system of ordinary differential equations for "SPH" particles. This is achieved by transferring local averaged information such as position, velocity, density, charge, current… to dynamical point elements. This mesh less numerical method easily handles boundaries (free or not) and is easily modified to include new physics.
Some recent applications to flows driven by magnetic fields are reviewed.

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Beryllium based films coatings for fusion applications

Abstract

The ITER-like Wall Project, part of the "JET programme in support of ITER", to be implemented on JET includes R&D activities to develop methods of depositing Be layers on inconel and marker tiles and characterization of the Be coating purity by surface and structure analysis techniques as well.

Two methods of Be deposition have been used to produce test samples: Thermionic Vacuum Arc (TVA) technique developed at National Institute for Laser, Plasma and Radiation Physics, Magurele and standard

thermal evaporation in vacuum developed at Nuclear Fuel Plant, Mioveni.

The principles of manufacturing processes and the properties of the Be coatings characterized by scanning electron and transmission electron microscopy, X-ray diffraction, X-ray photoelectron spectroscopy and atomic force microscopy will be presented.

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Modeling of plasma non-local transport using CTRW and fractional derivatives

Abstract

Understanding transport in magnetically confined plasmas is an outstanding issue in controlled fusion research. Despite significant advances, there are important unsolved open problems that are likely to play an important role in the design and operation of present and future magnetic confinement devices. A common trait of these problems is that they seem to defy our intuition rooted in the standard diffusion paradigm. Experiments showed evidence that the

response of tokamak discharges to a sharp drop in edge temperature differs significantly from that expected from local, diffusive transport models. Other perturbative experiments demonstrate nondiffusive responses and anomalously fast propagation of pulses. Further evidence of nondiffusive transport has come from off-axis heating experiments in which an inward flux of energy incompatible with diffusive models has been observed.

The objective in this study is using the CTRW theory in order to analyze the non-diffusive behavior observed in tokamak plasmas. On the one hand, one can investigate the effects of such non-diffusive transport of the plasma temperature and density on the characteristics of the unstable modes such as drift ITG/TE modes. On the other hand, one can use the approach used by fractional derivative models in order to include a non-diffusive transport in addition to the standard diffusive one. Both approaches are undergoing projects.

Charge dependence of impurity peaking factor

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Abstract

The problem of impurity transport in fusion plasmas is of extraordinary importance and is intensively studied for a long time both experimentally and theoretically. Nevertheless the experimentally found dependence of impurity transport characteristics, such as diffusivity and pinch velocity, on the impurity ion charge Z, see, e.g., Ref.[1], remains unexplained both by neoclassical and anomalous theoretical predictions. In this contribution the model for the impurity anomalous transport due to the ITG/TE unstable modes [2, 3, 4] has been developed further by taking into account the effects of impurity ion collisions with the main plasma components becoming more and more important with increasing impurity charge. In linearized transport equations [5] these effects are included as friction and thermal forces and collision energy exchange affecting perturbations of impurity ion parallel velocity and temperature, correspondingly. The results show that these terms, being proportional to

$Z^2 m_i / m_z$ provide the dependence of the impurity anomalous convection and the peaking factor $p = RV_z / D_z$. The numerical assessment is done for the plasma parameters typical to the central and edge plasmas in the tokamak JET. For the conditions of the plasma core, where the magnetic shear is low, the collisional effects are dominant in the pinch velocity and result in a very strong Z dependence of the impurity peaking factor. The sign and magnitude of the pinch-velocity and p depends essentially on the instability mechanism, i.e., ITG or TE drive. At the plasma edge, where magnetic shear is large, the pinch velocity contribution due to curvature effects, independent of Z, is of importance and the charge dependence of the impurity peaking factor is weaker than for the central plasma region. The results of calculations are compared with the experimental observations [6].

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Dispersion equation for ITG instability in plasma with ICRH

Abstract

The issue of transport in tokamak plasmas due to micro and macroinstabilities rests a major problem in physics of plasma fusion with many complex difficulties to solve. Besides turbulence, plasma interact with radio-frequency waves, largely used to heating plasma, which infuence the transport. Electron cyclotron resonance heating (ECRH) as well as ion cyclotron resonance heating (ICRH) power modulation have shown the effect of

heating on the anomalous pinch but also on the impurity transport.

The quasi-neutrality condition represents one of the fundamental equations used to describe the transport processes in plasma and permit to obtain the dispersion relation. The dispersion equation for the Ion Temperature Gradient instability is obtained for a multispecies tokamak plasma with ICRH. The electron density perturbation is assumed to be the adiabatic response to the electrostatic perturbation but ion/impurity density perturbation is evaluated from the gyrokinetic equation. The dependence of the dispersion equation on the charge of impurities is revealed.

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Modelling random transition between two temperature profiles

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Abstract

The evaluation of running diffusion coefficients is an important goal in fusion plasma physics as it provides a first insight into the transport properties of charged particles in electro-magnetic fields. Using Langevin equations we perform an analysis of the transport of the guiding centers of charge particles along and perpendicularly to the main magnetic field. The model includes collisions and therefore a thermal velocity which we relate to the plasma temperature evolution through a stochastic process, and a magnetic field represented by a different stochastic process which is considered independent of the thermal velocity. The combined effect of collisions and magnetic fluctuation in the zeros order guiding center approximation usually leads to particle subdiffusion in the perpendicular direction. We are considering modifications of this effect due to the transition between the two temperature states, with different radial profiles.

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The Zonal Flow in Anisotropic Weak Turbulence

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Abstract
The intermittency in particle transport at the plasma edge of fusion devices is a quite common feature. It is observed under many different confinement regimes including complex situations involving time dependent

evolution of transport barriers and zonal flows as demonstrated in [1]. In the framework of controlled nuclear fusion a central issue is the confinement of plasma by means of a magnetic field for a sufficient time in order to start the nuclear reactions. For this issue the understanding of the particle and energy cross-field fluxes is crucial for the control of unfavorable losses. The dominant mechanism of these losses appears to be the anomalous transport due to drift wave turbulence. This is caused to the unavoidable gradients of temperature and pressure present in the confinement devices, such as the tokamak. In turbulent plasma, the electrostatic potential, as well as the related quantities, have a continuously changing in time of their structure. If in a certain region there is a systematic *shear flow* in the poloidal direction, it will carry along *nonuniformly* the drift wave structures, thus deforming them. After some time the structure is torn up in the radial direction and fragmented into smaller substructures. This means that the various regions of the initial structure lose their correlation because of the drag by the shear flow. As a result, *an overall increase of the average wave vector of the structure is produced in the direction perpendicular to the shear flow.*
In a real situation (e.g., a tokamak), the situation is obviously more complex. In the case of isotropic electrostatic turbulence, under certain circumstances, the drift wave turbulence is able to generate spontaneously a shear flow in the poloidal direction. The average wave

vector of this flow is much smaller in the *y*-direction (poloidal direction in the tokamak) than in the *x*-direction (radial direction in the tokamak). This type of structure, which is elongated in the *y*-direction, is called *zonal flow.* The effect of this spontaneously generated zonal flow is explained like as a fragmentation of the drift wave structures in the radial direction.

An exhaustive presentation of the state of knowledge is given in the review paper [2]. The most natural way to study the zonal flow generation is by performing numerical simulations of the Hasegawa-Mima or of equivalent equations. We adopt here a different approach described in detail in [3] and which deals with the diffusive regime in the anisotropic weak turbulence case. The understanding of the anomalous particle transport therefore strongly depends on a detailed and adapted analysis, retaining non-Gaussian features, of the underlying turbulence. We consider specifically the zonal flow generated by an anisotropic electrostatic turbulence. As analytical tool, we adopt the decorrelation trajectory method since it is the only method that retains correlations beyond the Corrsin approximation. In the present work it is showed that the possible anisotropy of the turbulent environment plays an important role in the process of the generation of zonal flows. The diffusion coefficients, in physical space and in wave vector space, including all the possible couplings of these processes,

have been obtained. They provide us with an overview picture of the conditions for the zonal flow generation.

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Stochastic and regular dynamics in some models proposed for the study of the sawtooth phenomena in tokamaks

D. Constantinescu, M Negrea and I. Petrisor

Abstract
It is widely accepted that the sawtooth oscillations of the plasma parameters are closely related to the configuration of the magnetic field (for example they are observed when the safety factor falls below unity on the magnetic axis, i.e. when a q=1 magnetic surface first appears) but the determination of the magnetic field topology and of

the safety factor profile during the sawtooth instability is a difficult problem both theoretically and experimentally.

In [1] the sawtooth phenomenon is explained without a full reconnection, assuming the interaction of the (1, 1) mode with other periodicities. As the closest magnetic surfaces inside $q=1$ surface are locally reconnected to surfaces outside $q=1$, fast parallel thermal transport along the reconnected field lines leads to a sudden radial transport of energy out of the hot core. The crash duration begins at the first indication of the thermal transport through the $q=1$ surface and ends once the flux surfaces have returned to the unperturbed circular shape. In order to exemplify this scenario a model specific for the ASDEX-Upgrade magnetic configuration was used.

In the present work a magnetic configuration [2] was adapted in order to observe if the sawtooth scenario based on the magnetic reconnection in ASDEX-Upgrade tokamak [1] is reproducible for other magnetic configuration. In the new model we considered a non-local perturbation that contains not only the $m/n=1/1$ mode, but also higher harmonics: $m/n=2/2$ and $m/n=3/3$. The role of the additional perturbations during the partial sawtooth crash is observed.

The conclusion is that the scenario for the sawtooth magnetic reconnection presented in [1] is motivated by the general properties of Hamiltonian systems that involve a monotonous safety factor, so it is reproducible in many situations. The magnetic stochastization (and the

consequent radial transport of energy out of the hot core observed in the sawtooth crash) is due to the overlapping of (1, 1), (2, 2) and (3, 3) modes. It is crucial that the (1, 1), (2, 2), (3, 3) modes have the same rotation number, so they are situated in the same spatial region. In this case they lead to a much more effective destabilization of all low-order resonances inside the $q=1$ surface compared with the case of resonances located at the neighboring resonant surfaces. If q_0 increases, the stochastic region is reduced (because the number of the low-order resonances inside $q=1$ is reduced) and vanishes completely for $q_0=0.9$. In this situation the radial transport of energy is stopped (the end of the sawtooth crash). For a monotonous safety factor, the minimal value of the q-profile, q_0, increases in the sawtooth crash time between $q_{0,in}=0.7$ to $q_{0,fin}=0.9$

This scenario cannot be applied in the case of reversed shear safety factors, due to the specific properties of the safety factor. In this case an alternative scenario was proposed.

In the reversed-shear configuration the reconnection of the twin fixed points occurs for large values of q_0, for example $q_0=0.9<1$. The stochastization is due to the overlapping of the low-resonances that are situated near the (twin) surfaces $q=1$ (which becomes closer each other when q_0 is large).

For the reversed shear safety factors it is useful to decrease q_0 in order to retrace the non-chaotic behaviour because the distance between the twin $q=1$ surfaces increases and the overlapping phenomenon is reduced (in our model the regular behaviour is observed for $q_0=0.7$). In the reversed-shear sawtooth scenario the minimal value of the q-profile, q_0, decreases in the sawtooth crash time between $q_{0,in}=0.9$ to $q_{0,fin}=0.7$

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A strong obstruction to the existence of invariant tori in Hamiltonian systems

Abstract
KAM theorem ensures that most of tori persist after a slight perturbation of an integrable Hamiltonian system or an area preserving map. Computer experiments revealed that increasing the perturbation, the invariant tori disintegrate, one by one, until no invariant torus exists beyond a critical value. An open question is, why after a threshold no invariant torus can exist?

In this talk we argue that an obstruction to the nonexistence of an invariant torus is connected to the partial violation of monotonicity of a twist symplectic map (monotonicity in the sense defined by M Herman [École Polytechnique, Expose no 14,1988]). More precisely, after a large perturbation, that can be detected analytically, one creates a subregion in the phase space whose points have a fast rotational motion, that leads to the breakup. Unlike previous attempts to prove nonexistence of invariant circles in twist maps, we do not exploit only the variational description of orbits, but also the so called translation number about an orbit, and its connection to the Morse index of the Hessian of the action, associated to periodic orbits or segments of general orbits.

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On variable time-steping Runge-Kutta methods and approximation of attractors

Abstract

In applying continuous dynamical systems associated with systems of ordinary differential equations (o.d.e.'s) to concrete problems, numerical simulations are frequently used.

Whence the question of how accurately approximate the numerical results the exact solutions. This is the reason why in many papers with numerical methods discrete dynamical systems are associated. It is the analysis of these discrete dynamical systems that provides tools to measure the accuracy of approximation. In this field of

numerical analysis in dynamical systems is included our paper.

We prove that invariant sets of continuous dynamical systems, in particular attractors, are approximated by invariants sets of discrete dynamical systems associated to variable time-steping Runge-Kutta methods.

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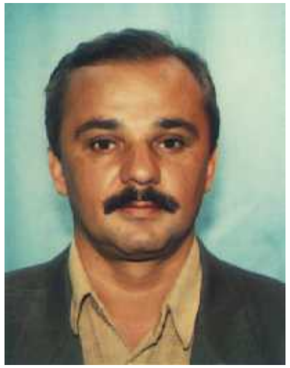

Aspects of the Diffusion in Tokamak Plasma

M. Negrea, I. Petrisor, Dana Constantinescu

Abstract
A central issue for fusion consists in the study of turbulence phenomena in plasma at high temperature. Magnetic turbulence appear as plausible candidates for the explanation of the anomalous transport properties of hot magnetized plasma. Our contribution deals with two problems: the study of the diffusion of stochastic magnetic field lines and the diffusion of ions moving in a stochastic magnetic field with curvature using the

Langevin equations of the guiding center approximation. In the first problem, we have studied the properties of magnetic field lines in the sheared slab approximation and the combined influence of a mean magnetic shear and of an anisotropy in the magnetic fluctuation spectrum in both the weak and the relatively strong stochastic regimes. We analyzed the influence of the magnetic Kubo number, the anisotropy parameter and the shear Kubo number on the diffusion of the magnetic field lines. The main conclusion is that the magnetic field transport is non-Gaussian for low fluctuation levels and Gaussian for high fluctuation levels. We generalize these last quoted studies by taking into account the magnetic shear and by using the decorrelation trajectory (DCT) method for a semianalytical calculation of the magnetic diffusion coefficients. Using the DCT method we were able to extend the analysis to a relatively high magnetic Kubo number, i.e. $K_m > 1$. Because of the existence of three parameters, namely, the magnetic Kubo number K_m, the shear parameter K_s and the anisotropy parameter, a rich class of transient behaviors of the diffusion coefficients in 'time' is observed. The competition between these parameters (two of the three are independent) is decisive in the determination of the trapping effects observed with the help of the DCT trajectories. We also calculate global Lagrangian average quantities such as the mean fluctuating magnetic field components, the mean magnetic potential and mean field line velocities. A finite

asymptotic constant average velocity is obtained for all values of the parameters. In the second problem we have shown that the magnetic stochastic drifts provide a decorrelation mechanism of the particles from the magnetic lines. Because the Corrsin approximation ignores the trapping effect that necessarily exists in relatively strongly turbulent plasma, the method of the decorrelation trajectories was applied. It was shown that the trapping effect is more pronounced, the larger drift Kubo number is. The diagonal coefficients start with a linear part, defining a ballistic regime followed by a trapping regime before reaching the saturation asymptotic value. Thus the global trapping effect is enhanced at larger drift Kubo number; the stochastic magnetic drift has practically the same influence on ion's diffusion as the magnetic shear on the intrinsic diffusion of magnetic field lines.

References

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Numerical methods for kinetic equations

Abstract

Two main approaches are used for plasma numerical simulations: the fluid and the kinetic approaches. Fluid methods (like the MHD method) describe the macroscopic evolution of the plasma, but they become inaccurate for problems in which the detailed kinetic processes affect the macroscopic behavior of the plasma. The second approach is kinetic and looks to find the behavior of the plasma using kinetic equations. This approach models accurately the plasma from first principles but is computationally expensive. Often, the macroscopic evolution of a plasma that develops relatively slowly is strongly coupled with smaller and

faster phenomena where kinetic effects are predominant (magnetic reconnection for instance). With the present huge increase of both computing power (High Performance Computing – HPC, i.e., applications of cluster-based computing) and parallelization algorithms, kinetic simulations become practically very attractive.

Implicit Maxwell Solver. Computing the self-consistent motion of a large number of charged particles in the fields they produce, one can simulate the full complexities of plasma from first principles. The basic difficulty in solving the first-order Maxwell's equations is related to the fact that these equations comprise a system of eight equations for six unknowns (assuming given charge and current densities). It is incorrect to consider the divergence equations redundant, based on that the divergence conditions will be satisfied if they are initially. Ignoring the divergence conditions leads to incorrect solutions of Maxwell's equations. The second-order formulation of Maxwell's equations (derived from the first-order equations by applying the curl operator) admit more solutions than their original ones and do not satisfy the divergence constraint too. Implicit simulations are useful for the study of low-frequency phenomena (because they eliminate many numerical stability constraints on time and space steps) and realistic electron-ion mass ratios. Implicit plasma simulations require the solution of the Maxwell equations in the presence of a permittivity in form of a non-symmetric

tensor. The solution of Helmholtz equations needs the divergence condition to be enforced on an associated part of the boundary to exclude the infinite degenerate eigenvalue in time-harmonic cases and to guarantee the accuracy of the numerical solution for time-varying cases.

Particle In Cell Method. Particle in cell (PIC) methods have emerged over years as the most effective tool for kinetic plasma simulation. In such methods, the physical system is studied by means of a reduced set of computational particles, each one representing a very large number of real particles. Such particles are characterized by a set of variables like mass, electric charge, position and velocity. Due to the statistical nature of this particle method – the computational model is composed of far fewer particles than the real plasma - PIC methods present a level of noise. An approach to reduce the noise is the δf method, in which only the perturbation from the equilibrium distribution is investigated with the computational particles. Unfortunately, many physical systems can not be described in terms of perturbed equilibrium only. Another major problem is related to the systems where multiple scale lengths are present (shocks or sheets at the boundaries) and the plasma present local, rapid variations in small portions of the system. A possible approach for such cases could be the use of non-uniform or adaptive grids, with fine grids spacing in the regions of strong

gradients and larger spacing where variations are mild. Finite element and finite differences can be used in such view. In PIC methods it is not sufficient to use adaptive grids with finer spacing in the regions of interest, but it is also necessary to rezone the number of particles, i.e., to increase the number of particles in regions where high accuracy is necessary and to reduce the number of particles where lower accuracy is acceptable. Thus, finer grid spacing gives a better description of the electromagnetic fields while particle rezoning leads to a better description of the plasma dynamics.

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Applications of Symmetry Methods for Hasegawa – Mima equation

Abstract

The theory of plasma physics offers a number of nontrivial examples of partial differential equations, which can be successfully treated with symmetry methods. We propose to apply the Lie symmetries method to the case of Hasegawa--Mima equation, that describes strong turbulence in magnetized nonuniform plasma in the ATC tokamaks.

We found by this method that the Hasegawa-Mima model, which, in general, is not self similar, has exact asymptotic self similar solutions.