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Université Claude Bernard (Lyon 1)

Activity Report 2014

Project-Team KALIFFE

Kinetic models AppLIed for Future of Fusion Energy

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Earth, Environmental and Energy Sciences

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Project-Team KALIFFE

Keywords: Scientific Computation, Simulation, Statistical Physics

The Inria team "Kaliffe" gathers researchers, engineers and teachers from the Université Claude Bernard, Lyon 1.

Creation of the Project-Team: 2014 July 01.

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2. Overall Objectives

2.1. Overall Objectives

Controlled fusion is one of the major challenges of the 21st century that can answer the need for a long term source of energy that does not accumulate wastes and is safe. The nuclear fusion reaction is based on the fusion of atoms like atoms of deuterium and tritium. This reaction does not produce long-term radioactive wastes, unlike today's nuclear power plants which are based on nuclear fission.

In order either to achieve a sustained fusion reaction or simply to obtain a positive energy balance, it is necessary to confine sufficiently the plasma for a long enough time. This is one of the main issue in the ability to produce energy from fusion reaction. If the confinement density is higher, the confinement time can be shorter but the product of both quantities needs to exceed some threshold values.

Two major research approaches are currently followed towards the objective of fusion based nuclear plants and both of them will be considered in the present project KALIFFE :

- Magnetic Fusion (ITER Program in Cadarache). The idea behind magnetic fusion is to use large toroidal devices called tokamaks in which the plasma can be confined thanks to large applied magnetic field. The international project ITER is based on this idea and aims to build a new tokamak which could demonstrate the feasibility of the concept.
- Inertial Confinement Fusion (ICF - Laser Méga-Joules in Bordeaux). The inertial fusion concept consists in using intense laser beams or particle beams to confine a small target containing the deuterium and tritium atoms. For instance, the Laser Mégajoule which is being built at CEA in Bordeaux will be used for experiments using this approach

Both approaches lead to study hot plasmas, which constitute an important field in physics and applied mathematics, spanning many different length and time scales. Accurately simulating hot plasmas requires solving the physics of hydrodynamics, radiation and electron transport, wave-wave interactions, wave-particle interactions and particle-particle interactions, to name a few processes.

Performing such a calculation that solves such physics at all these length and time scales remains computationally unfeasible even with an exa-scale capability. Thus, it is important to differentiate between the physics that must be fully solved, and the physics that can be included with a reduced model description in a fully integrated simulation.

This project is intended to be focused on the fundamental computational challenges that arise when simulating high energy plasmas. This includes aspects of five and six-dimensional formulations of plasma transport theory, plasma-waves interactions, and the design of robust analytic techniques for software verification. These are all "multi-physics" problems, involving electromagnetic interactions, turbulent fluid behavior, and collisions. These problems are also "multiscale", requiring multi-resolution and hybrid algorithms coupling the different scales. Therefore, different numerical methods for the simulation of the governing integro-differential equations that scale with problem size and are suitable for high-performance computing will be developed. This work in modeling and numerical simulation of plasmas will be applied to problems like fast ignitor concept in the laser fusion research. Another application is devoted to the development of Vlasov codes in a toroidal configuration in the framework of the magnetic fusion program in collaboration with several Inria projects.

3. Research Program

3.1. Numerical schemes for nonlinear kinetic models in an arbitrary geometry

In this part, we want to focus in the numerical approximation of solutions to kinetic equations (microscopic description) set in a complex geometry with different types of boundary conditions. Many numerical schemes have been proposed to approximate the solutions of nonlinear kinetic equations, but few of them are concerned by the treatment of complex geometry and boundary conditions which have a special interest for applications. In this context, classical structured or unstructured meshes already applied in computational fluid dynamics are not appropriate due to the high dimensional property of kinetic problems. In contrast, the Cartesian mesh makes the numerical method efficient and easy to implement. Indeed, in the framework of the Inria-Calvi project, E. Sonnendrücker and his collaborators have developed several families of methods for solving transport equations in a phase space grid with specific applications to plasma physics. These methods are based on the well known semi-Lagrangian methods. The principle is to solve the equation on a phase space grid, for which the grid points are advected with the flow of the transport equation for a time step and interpolated back periodically on the initial grid. The characteristics can be solved either forward or backward in time leading to the forward semi-Lagrangian or backward semi-Lagrangian schemes. These schemes are particularly well suited for uniform Cartesian grid since they are efficient in term of accuracy (high order scheme), stability (not restricted by a CFL condition) and computational cost (fast to locate the transported grid point).

Our aim is now to use all these techniques in the context of complex geometry and for the treatment of boundary conditions. The difficulty is that obviously grid points are usually not located on the physical boundary when using a Cartesian mesh, thus a suitable numerical method to capture the boundary condition on the complex geometry is required. In order to apply numerical methods previously studied, we want to treat separately the transport equation and the boundary conditions in the complex geometry.

Several numerical methods based on Cartesian mesh have been developed in computational fluid dynamics in last decade. Among these methods, the immersed boundary method (IBM), first introduced by Peskin for the study of biological fluid mechanics problems, has attracted considerable attention because of its use of regular Cartesian grid and great simplification of tedious grid generation task. The basic idea of immersed boundary method is that the effect of the immersed boundary on the surrounding fluid is represented through the introduction of forcing terms in the momentum equations. In conservation laws, two major classes immersed

boundary like methods can be distinguished on different discretization types. The first class is Cartesian cut-cell method, which is based on a finite volume method. This conceptually simple approach "cuts" solid bodies out of a background Cartesian mesh. Thus we have several polygons (cut-cells) along the boundary. Then the numerical flux at the boundary of these cut-cells are imposed by using the real boundary conditions. This method satisfies well the conservation laws, however to determine the polygons is still a delicate issue.

Here, we will consider another class of method, based on finite difference method. To achieve a high order interior scheme, several ghost points behind the boundary are added. For instance for solving hyperbolic conservations laws, an inverse Lax-Wendroff type procedure is used to impose some artificial values on the ghost points. The interest of this approach is that it preserves all the flexibility of semi-Lagrangian schemes, that is, high order accuracy, resolution in a uniform Cartesian grid and stability. The members of the project involved in this thematic pole are already studying kinetic and related models and will develop this type of numerical schemes focusing on the following goals:

- **Accuracy.** Achieving arbitrary high accuracy for problems with smooth solutions has been a topic of the utmost importance in the recent years and actively studied by a many researchers and groups worldwide. The project team has been investigating such methods for several years and for various PDE models, for steady and unsteady physical problems, using different formulations among which spectral and semi-Lagrangian methods, discontinuous Galerkin methods and finite volume methods. In all the cases, we consider numerical methods relying on discretization techniques that best fit to the geometrical characteristics of the problems at hand.
- **Robustness.** On the other hand, these methods should also be capable to accurately describe the underlying physical phenomena that may involve highly variable space and time scales. With reference to this characteristic, several strategies are possible: adaptive local refinement/coarsening of the mesh (*i.e* h-adaptivity) and adaptive local variation of the interpolation order (*i.e.* p-adaptivity). Ideally, these two strategies are combined leading to the so-called hp-adaptive methods and that will actually represent an ultimate objective of our research activities. Note that both strategies are all local in nature.
- **Efficiency.** Despite the ever increasing performances of microprocessors, the numerical simulation of realistic $4D$ or $5D$ kinetic problems is hardly performed on a high-end workstation and parallel computing is a mandatory path. Hence, numerical methods must be adapted to the characteristics of modern parallel computing platforms taking into account their heterogeneity and their hierarchical nature (*e.g.* multiple processors and multiple core systems with complex cache and memory hierarchies, possibly augmented with accelerator cards). Appropriate parallelization strategies need to be designed that combine distributed memory and shared memory paradigms *i.e.* MIMD (multiple instruction, multiple data) and SIMD (single instruction, multiple data) programming models.

3.2. Asymptotic Preserving schemes

We develop robust numerical schemes for kinetic equations that also work in the fluid regime. The goal of this part of the project is to propose a new general and systematic strategy that avoids the inversion of the involved time implicit schemes and that allows to apply the microscopic description without any stability constraint on the numerical parameter h.

Development of numerical schemes for stiff problems.

The idea is to combine micro/macro decomposition with penalization techniques for collision operators, leading to completely explicit schemes which are stable in the desired macroscopic limits. The expected schemes should be consistent with the model at both macroscopic and microscopic levels.

However for plasma applications, the Landau-Fokker-Planck operator has a diffusion structure in the velocity variable which induces special behaviors at both mathematical and numerical levels. We will show that the previous methodology can be adapted to overcome the velocity diffusion stiffness in this case. In other words, the obtained numerical schemes are expected to be free of usual diffusion CFL conditions, and will be stable and consistent within the macroscopic limit under consideration. Finally, to decrease the computational cost

of the so constructed schemes, which is due to the non local character of the involved collision operator (Boltzmann, Landau, etc), fast computational method for integral operator are needed. On the basis of multi-grid and/or Fast Multi-pole Methods, we shall develop appropriate acceleration methods to our context.

Another important task in this project is to extend the above strategy to the context of a self-consistent Poisson or Maxwell equations. Accurate methods based on finite volume schemes will be developed for high field limit. A stiffness raised by the presence of high electromagnetic fields will also be treated in the same spirit. Such problems are also investigated in the IPSO project (M. Lemou, F. Méhats and N. Crouseilles). Here our strategy is based on a suitable operator decomposition coupled with appropriate IMEX schemes.

Stability and accuracy issue. In the framework of Asymptotic-Preserving (AP) schemes, there are few mathematical justifications of stability and uniform accuracy of such approach. A stability analysis has to be performed to rigorously prove that the numerical scheme is stable for small values of small physical parameters even if the time step does not resolve it. This analysis seems to be tricky for fully nonlinear kinetic equations like the Boltzmann equation. Therefore, we focus on simpler models as discrete velocity models (DVM) which have the same properties as the full Boltzmann operator but deal with a finite set of velocity. In this project we are particularly interested by the long time behavior of the numerical solution when it approaches its stationary state. We plan to apply the entropy-entropy dissipation technique to design new numerical approximations. It gives a specific discretization based on finite volume approximation, which allows to control the numerical entropy production and in some situations, it is often enough to give stability of the numerical solution in the long time asymptotic limit. For general cases, these estimations have to be completed by some discrete functional inequalities.

4. Application Domains

4.1. Plasma Physics and fusion energy

Taking into account spatial effects and time evolution of hot plasmas therefore leads to severe numerical challenges first on modeling aspects and second on purely numerical issues like oscillations and multiscale phenomena. Time scales are very different, ranging from pico-seconds to seconds. This requires special treatment to avoid excessive computing time, as for instance slow/fast manifold decomposition or time averaging. These two difficulties lead to the study and development of new robust numerical schemes and algorithms in order to preserve accuracy and stability within reasonable computing time. To speed up model development the use of refined numerical schemes must be as automatized as possible. Slow/fast manifold should be constructed automatically from the model, and spatial discretization should be as transparent as possible in order to apply former works (semi-Lagrangian or particle methods for transport, spectral or finite difference methods for collisions) on this topic.

Our program can be split into three different tasks :

- derivation of new collision operators based both on Coulombian interactions and strong external forces, approximation of collisional operators for multi-species by developing fast algorithms ;
- numerical treatment of multi-scale problems applying AP schemes to problems taking into account electromagnetic effects and collisions ;
- hybrid methods to take advantage of different regimes and reduce the computational cost.

Approximation of collision operators in plasma physics & conception of softwares for collisional plasmas.

An important step in the understanding of high temperature and dense plasmas is to investigate the effect of weakly Coulombian interactions, namely the Landau or Landau-Fokker-Planck collision operator. Due to the high temperature, collisions between particles have been neglected most of the time, but for the long time simulations, it seems that collisions may contribute and induce some nonlinear effects stabilizing the plasma. Furthermore, for inertial and magnetic confinement fusion, classical collision operators are no longer valid since their derivation, based on microscopic interactions only take into account self-interactions but no external forces, which are not negligible in our applications. There are only few works of physicists on this topic in 80's.

Then, our objective is to derive such operators to describe collisional plasmas and to simulate the transport of classical, as well as relativistic electrons, within a multi-species plasma, containing mobile electrons and ions. Issues to be addressed on this topic involve the derivation of multi-scale models due to different scales of effective constants, spatial heterogeneity and strength of boundary conditions.

Moreover, because of the quadratic aspect of the kernel and the multiple integrations in its analytical formulation, the Landau-Fokker-Planck equation is complicated to compute even if fast algorithm are available O($N \log N$), where N is the number of degree of freedom. Henceforth, different simpler models have been introduced, especially the BGK model which is mainly a relaxation towards a Maxwellian equilibrium state, or the linear Fokker-Planck which is a diffusive operator or a nonlinear Fokker-Planck operator taking into account Coulombian interactions. Although, these operators describes correctly the hydrodynamical limit, they usually do not give the correct transport coefficient in the Chapman-Enskog expansion. Our interest here is to compare the different operators in the description of binary collisions between ions-electrons or electrons-electrons and to select the one which is adapted with respect to the physical situation.

Collisional plasma and fluid models One characteristic of plasma physics problems is that they involve many different phenomena (instabilities, saturation phenomena due to nonlinear effects which couple different modes), many different time (plasma frequency, girokinetic frequency, etc) and space scales. Splitting a model in sub-models and studying their interactions is a central point, leading to new questions: how to define sub-models? How to simplify or complexify them?

For instance, the interaction of intense lasers with solid matter generates a hot plasma state that is well described by the Vlasov-Maxwell equation at the ignition point, whereas collective effects (electromagnetic fields) and collisions have to be taken into account around the impact and fluid models are sufficient in the capsule (see Figure 1). Accurate and efficient modeling of the physics in these scenarios is highly pertinent, because it relates to experimental campaigns to produce energy by inertial confinement fusion on facilities such as the Laser Méga-Joules in Bordeaux. Calculations involving the Vlasov-Fokker-Planck equation are computationally intensive, but are crucial to proper understanding of a wide variety of physical effects and instabilities in inertial fusion plasmas.

One of the main challenges from the numerical point of view is to propose a general methodology to design macroscopic fluid models that take into account localized kinetic up-scaling effects (which represents the meso-scale). One approach will consist in considering fluid models, which are solved in the whole domain together with a localized kinetic upscaling that corrects the fluid model wherever it is necessary (non-equilibrium events occurring in the flow). This upscaling is obtained by solving a kinetic equation on the non-equilibrium part of the distribution function. This equation is solved only locally and is related to the fluid equation through a downscaling effect. We want to demonstrate that this approach applies to problems that have a hydrodynamic time scale as well as to problems with diffusion time scale.

The project will therefore combine physical modeling and mathematical analysis in order to achieve an understanding and propose a model of the plasma behavior over the various scales involved. The milestones involved in this project are therefore:

- set up a new phenomenology allowing to describe non-local effects in any geometry, and based on a state-of-the-art of mathematical modeling of hot plasmas;
- set up a multiscale model of the physical mechanisms at play at the different scales (micro, meso and macro scales), with a crucial emphasis on the connections between the scales ;
- propose a mathematical analysis and numerical development of the models, and provide systematic derivations of the connections between the scales.

This program therefore organizes naturally over the various scales at play in the problem and their connections: macroscale phenomenology ; kinetic at mesoscales ; statistical behavior at microscales.

5. New Software and Platforms

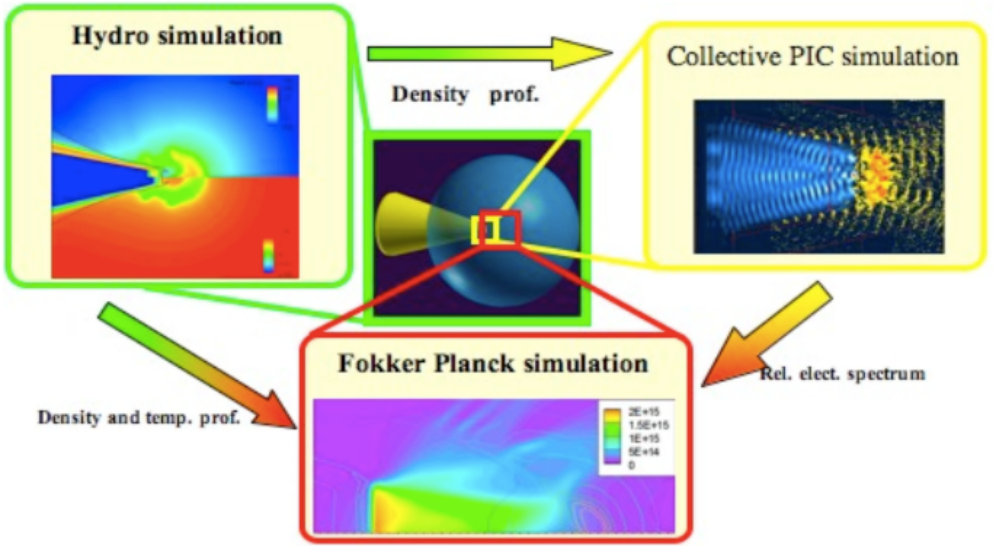


Figure 1. Multiscale modeling at higher laser intensities corresponding to the fast ignition approach for Inertial Confinement Fusion : a relativistic treatment should be considered and collision operators with a large energy exchange are required.

5.1. New Softwares

5.1.1. Hope : High Order Program for Energy

This software is focused on the numerical simulation of 2D transport equation using fully deterministic methods (high order finite difference solvers, semi-Lagrangian methods).

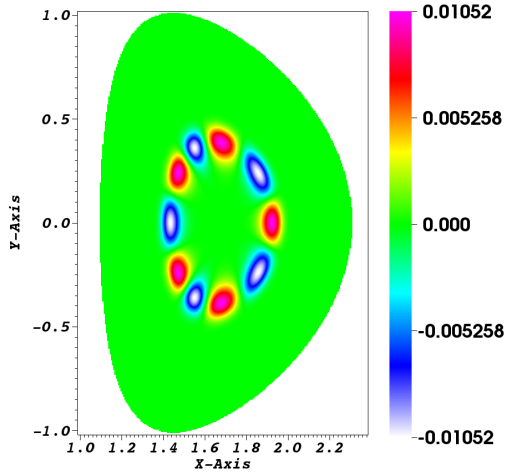
Numerical simulation of guiding center model [9]

We consider the diocotron instability for an annular electron layer. This plasma instability is created by two sheets of charge slipping past each other and is the analog of the Kelvin-Helmholtz instability in fluid mechanics. We propose a comparison of two different numerical methods : the mixed method (top): this method uses alternatively a semi-Lagrangian and finite difference method with fifth order Hermite WENO reconstruction. The choice is made automatically according to a good preservation of mass (the finite difference method is conservative). the semi-Lagrangian (bottom): this method is based on a cubic spline interpolation for the reconstruction of the distribution function.

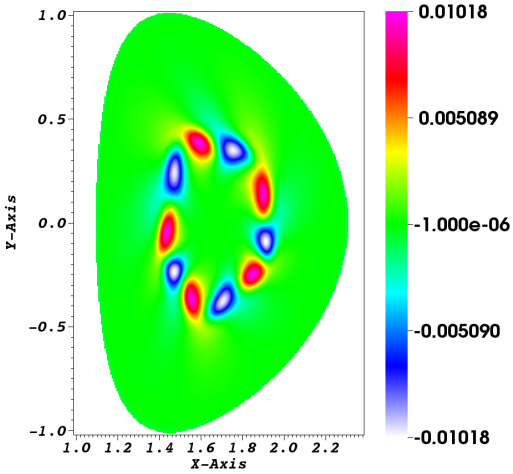
Numerical simulation in a D shape [9]

This simulation illustrates an instability development of the solution to the guiding-center model in a D-shaped domain. We present the difference between the perturbed density and the steady state density. An instability develops and generates small filaments. It correspond to the motion of the density in the transverse plane of the tokamak.

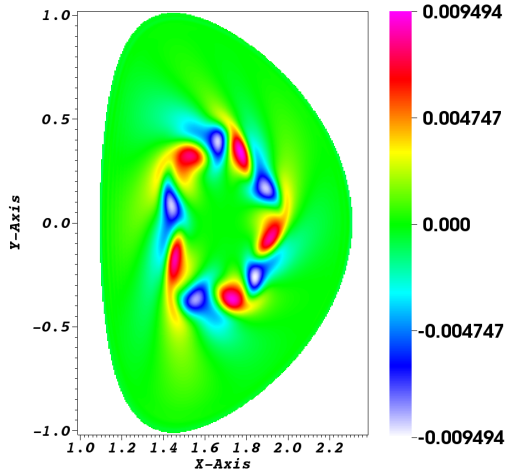
Figure 2 illustrates the evolution of density governed by the guiding-center model. We present the difference between the perturbed density and the steady state density, *i.e.* $\delta\rho(t) = \overline{\rho}(t) - \overline{\rho}_0$. We observe that the difference of density $\delta\rho$ revolves, and small filaments appear at time $t = 200$. Until the time $t = 300$, we can clearly identify the filaments.



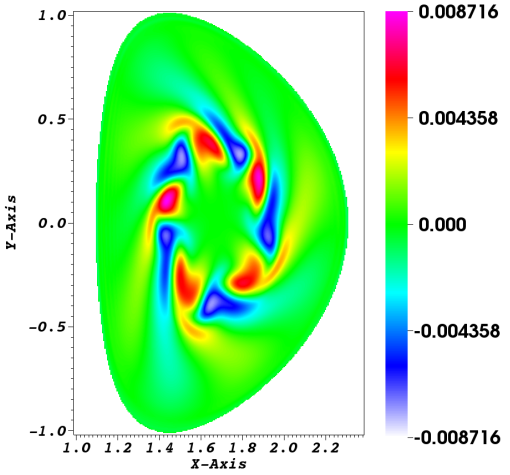
(a) $t = 0$



(b) $t = 100$



(c) $t = 200$



(d) $t = 300$

Figure 2. Instability simulation for guiding-center model in D-shaped domain. The difference between the perturbed density and the steady state density is presented, i.e. $\delta\rho(t) = \overline{\rho}(t) - \overline{\rho}_0$.

5.1.2. Towards 4D numerical simulations

The discretization of the Drift-Kinetic model can be developed very similarly as the one for the guiding-center model. Here, we present some principle discretization steps.

The Vlasov equation of system can be split into three equations :

$$\begin{cases} \dfrac{\partial f}{\partial t} + \mathbf{U} \cdot \nabla_{\mathbf{x}_\perp} f = 0, \\ \dfrac{\partial f}{\partial t} + v_\parallel \partial_z f = 0, \\ \dfrac{\partial f}{\partial t} + E_\parallel \partial_{v_\parallel} f = 0. \end{cases}$$

This test represents a snapshot of the charge density when an instability occurs (ion turbulence simulation). This simulation has been realized by different methods but in cylindrical coordinates, here we perform numerical simulation in Cartesian coordinates on a uniform grid. The discretization of the Drift-Kinetic model can be developed very similarly as the one for the guiding-center model.

6. New Results

6.1. Mixed semi-Lagrangian/finite difference methods for plasma simulations

We present an efficient algorithm for the long time behavior of plasma simulations. We will focus on 4D drift-kinetic model, where the plasma's motion occurs in the plane perpendicular to the magnetic field and can be governed by the 2D guiding-center model.

Hermite WENO reconstructions are applied for solving the Vlasov equation. Here we consider an arbitrary computational domain with an appropriate numerical method for the treatment of boundary conditions.

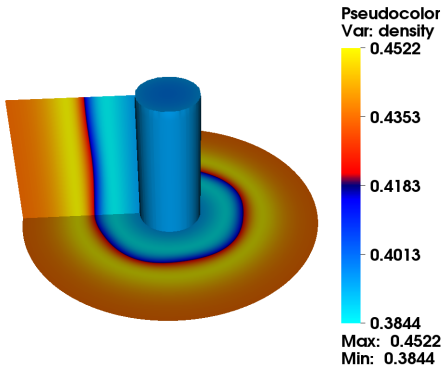
Then we apply this algorithm for plasma turbulence simulations. We first solve the 2D guiding-center model in a D-shape domain and investigate the numerical stability of the steady state. Then, the 4D drift-kinetic model is studied with a mixed method, *i.e.* the semi-Lagrangian method in linear phase and finite difference method during the nonlinear phase. Numerical results show that the mixed method is efficient and accurate in linear phase and it is much stable during the nonlinear phase. Moreover, in practice it has better conservation properties [9].

6.2. High order semi implicit schemes for PDEs

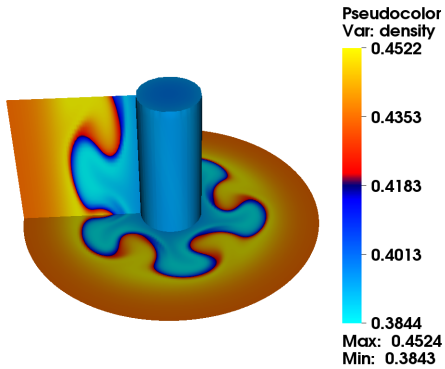
We consider a new formulation of implicit-explicit (IMEX) methods for the numerical discretization of time dependent partial differential equations. We construct several semi-implicit Runge-Kutta methods up to order three. This method is particularly well suited for problems where the stiff and non-stiff components cannot be well separated. We present different numerical simulations for reaction-diffusion, convection diffusion and nonlinear diffusion system of equations. Finally, we conclude by a stability analysis of the schemes for linear problems.

6.3. A Hierarchy of Hybrid Numerical Methods for Multi-Scale Kinetic Equations

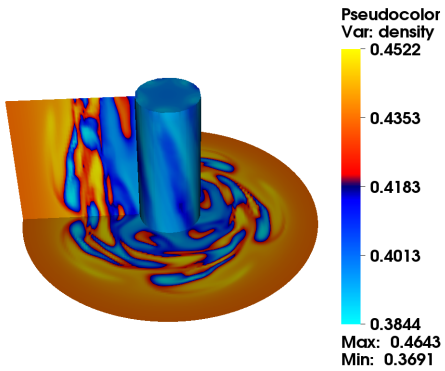
We construct a hierarchy of hybrid numerical methods for multi-scale kinetic equations based on moment realizability matrices, a concept introduced by Levermore, Morokoff and Nadiga. Following such a criterion, one can consider hybrid scheme where the hydrodynamic part is given either by the compressible Euler or Navier-Stokes equations, or even with more general models, such as the Burnett or super-Burnett systems [8].



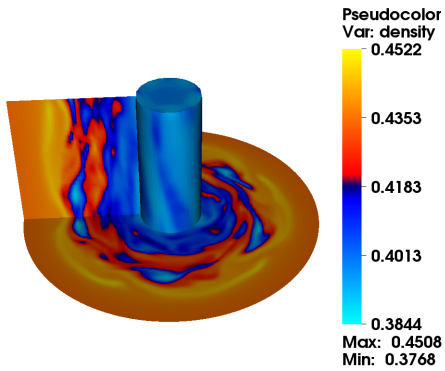
(a) $t = 2000$



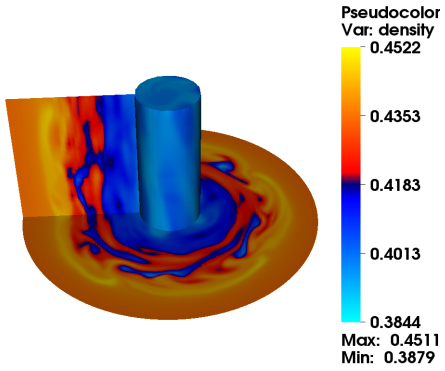
(b) $t = 3000$



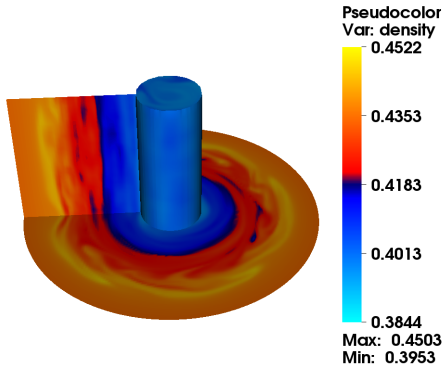
(c) $t = 4000$



(d) $t = 5000$



(e) $t = 6000$



(f) $t = 8000$

Figure 3. Evolution of ion turbulence. The distribution function is shown for the velocity $v_{||} = 0$. The mesh size is $n_x = n_y = 128, n_z = 32, n_v = 65$. Mixed Semi-Lagrangian/finite difference method is used.

6.4. Derivation of high order absorbing boundary conditions for the Helmholtz equation in 2D

We present high order absorbing boundary conditions (ABC)for the Helmholtz equation in 2D, that can adapt to any regular shapedsurfaces. The new ABCs are derived by using the technique ofmicro-diagonalisation to approximate the Dirichlet-to-Neumann map.Numerical results on different shapes illustrate the behavior of thenew ABCs along with high-order finite elements [5].

7. Partnerships and Cooperations

7.1. National Initiatives

7.1.1. ANR

Our group participates to the following ANR projects with different colleagues of us in Lyon

- ANR STAB on stability for the asymptotic behavior of PDEs, stochastic processes and their discretization. The Principal Investigator is I. Gentil (UCB Lyon) and F. Filbet is a participant.
- ANR BOND on boundaries, numerics and dispersion. The Principal Investigator is S. Benzoni (UCB Lyon) and L. M. Rodrigues is a participant.
- ANR de groupe "*Highly-Efficient ATmospheric modelling*" (HEAT), 2014–2018. The Principal Investigator is Th. Dubos and D. Le Roux is a participant.

On the other hand, we have submitted a projet on the call 2015 on adapted dynamic and multi-scale methods. F. Filbet, M. Bergot are participants.

7.2. European Initiatives

7.2.1. FP7 & H2020 Projects

This is the last year of the ERC Project Nusikimo devoted to the mathematical and numerical analysis in statistical physics with a special interest to applications in Plasma Physics (CEA-CELIA laboratory in Bordeaux, where the Mega-Joule Laser is built) and micro-technology with MEMS (university of Catania). Our project gathers young researchers in applied mathematics from the group in Mathematical Modelling and Scientific Computing in Lyon.

7.2.2. Collaborations in European Programs, except FP7 & H2020

Program: Eurofusion - Enabling Research Project for the implementation of the fusion roadmap

Project acronym: Verification of global gyrokinetic code.

Project title: Verification of global gyrokinetic codes and development of new algorithms for gyrokinetic and kinetic codes.

Duration: 1 year.

Coordinator: E. Sonnendrücker.

Other partners: Max Planck Intitute (Garching, Germany).

Abstract: The aim of this proposal the improvement of the numerical methods for gyrokinetic models and to investigate new ideas towards fully kinetic simulations of tokamaks and stellarators. It consists of three main parts: the first is devoted to the definition of verification models that enable to verify that the implemented codes are a good approximation to a given continuous model and that contain the most challenging numerical problems in the most simple possible setting. New benchmarks of the codes will also be performed. The second part is devoted to the improvement of each category of codes and the third to experimenting new ideas that can lead to better codes in the longer term

7.3. International Initiatives

7.3.1. Inria International Partners

Our team is a partner on the CoKLyCo project. It is the acronym of the project COffee-Kyoto-LYon-COperation. The project if funded by Inria, through its International Affairs programs and the Japan Society for the Promotion of Science (JSPS), through the cooperation program AYAME (Wink: Ayame means iris. . .).

Kinetic theory plays a central role in many areas of mathematical physics, from nanoscales to continuum mechanics. It is an indispensable tool in the mathematical description of applications in physical science from its origin in dilute gases, to wide applications such as semiconductors, polymers, cells, plasma, galaxies, traffic networking, and swarming. Many challenges remain in both the analysis and efficient computational techniques for such problems. The project is concerned with the modeling of rarefied gas dynamics for Micro-Electro-Mechanical Systems. The design of such devices with tiny scales leads to new questions related to the intricate particles/structures interactions. Strongly motivated by the specific technological content, we wish to develop original computational tools, based on rigorous mathematical basis. This project is therefore concerned with the mathematical analysis and the numerical simulation of systems of PDEs of kinetic type, or their hydrodynamic counter-part, set in a moving domain. In 2014, we started working on several aspects of these questions, owing to a couple of visits and meetings during conferences, like the one in CIRM, Nov, 2014.

7.3.1.1. Informal International Partners

- F. Filbet collaborates with J. M. Qiu from the University of Houston on positive method for Vlasov type models.
- F. Filbet collaborates with G. Russo and S. Boscarino at University of Catania (Italy) on high order numerical schemes for time evolution equation and with L. Pareschi at the University of Ferrara (Italy) on spectral methods for Boltzmann equations [7].
- L. M. Rodrigues collaborates with M. Johnson (Kansas University) and K. Zumbrun (Indiana University) and their group on stability issues and asymptotic model reduction.

8. Dissemination

8.1. Promoting Scientific Activities

8.1.1. Scientific events organisation

8.1.1.1. general chair, scientific chair

F. Filbet was in the scientific committee of "12e Colloque Franco-Roumain en Mathématiques Appliquées" which was organized in Lyon in august 2014.

8.1.1.2. member of the organizing committee

D. Le Roux was in the organizing committee of "12e Colloque Franco-Roumain en Mathématiques Appliquées" which was organized in Lyon in august 2014.
F. Filbet was in the organizing committee of "Journées Modélisation Mathématiques et Calcul Scientifique" at Vapré (Ecully) from 18-19 dec. 2014.

8.1.2. Journal

8.1.2.1. member of the editorial board

F. Filbet is a member of the editorial board of the journals Confluences Mathematicae and ESAIM-Proceedings.

8.1.2.2. reviewer

- F. Filbet served a a referee for J. Comp. Phys., SIAM, J. Sci. Comput., SIAM J. Num. Anal., Comm. Comput. Phys., J. Sci. Comput., Comp. Applied. Math.s, AMS Math. Comp.
- L.M. Rodrigues served as a referee for Arch. Ration. Mech. Anal., Comm. Math. Phys., Phys. D.
- D. Le Roux served as a referee for AGU Book Series, Communications in Numerical Methods in Engineering, Computer Methods in Applied Mechanics and Engineering, Computers and Fluids, International Journal for Numerical Methods in Fluids, Journal of Computational Physics, SIAM Journal on Scientific Computing, Mathematics and Computers in Simulation.

8.2. Teaching - Supervision - Juries

8.2.1. Teaching

Our group is stronly involed on teachin activities at Polytech Lyon and at the Department of Mathematics (UCB Lyon).

Licence : M. Bergot (Numerical Analysis, Calculus, 192 h), S. Delcourte (Numerical Analysis, Calculus, 192 h), F. Filbet (Calculus, 52h), S. Delcourte and E. Fouassier (PDE, Analysis, Calculus, 192 h), L. M. Rodrigues (Numerical Analysis, Calculus, 192 h)

Master : F. Filbet (Kinetic Theory, PDE and numerical analysis, 36h), D. Le Roux (Fluid mechanics, PDE and numerical analysis, 36h).

F. Filbet is co-director of the PhD program in Computer Sciences and Mathematics of Lyon (ENS, INSA, ECL, UCBL, UFLL, UJML).

8.2.2. Juries

- F. Filbet was referee of 5 PhD for Univ. Paris Dauphine - Paris IX, Univ. P. & M. Curie - Paris VI, Univ. Paris Sud- Paris XI, Univ. Bordeaux, Univ. Kaiserslautern (Germany).
- D. Le Roux was in the « jury » of F. Marche (Université de Montpellier), E. Ngom, J. Demange (Université de Grenoble), M.M. Tuhan, K.T. Kouakou (Université Nangui Abrogoua, Abidjan, Côte d'Ivoire)

9. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

[1] M. BESSEMOULIN-CHATARD, C. CHAINAIS-HILLAIRET, F. FILBET. *On discrete functional inequalities for some finite volume schemes*, in "IMA Journal of Numerical Analysis", July 2014, pp. 10-32 [*DOI :* 10.1093/IMANUM/DRU032], https://hal.archives-ouvertes.fr/hal-00672591

[2] F. FILBET, C. YANG. *Numerical Simulations of Kinetic Models for chemotaxis*, in "SIAM Journal on Scientific Computing", 2014, vol. 36, n^{o} 3, pp. B348-B366, https://hal.archives-ouvertes.fr/hal-00798822

[3] M. A. JOHNSON, P. NOBLE, L. M. RODRIGUES, K. ZUMBRUN. *Behavior of periodic solutions of viscous conservation laws under localized and nonlocalized perturbations*, in "Inventiones Mathematicae", 2014, vol. 197, n^{o} 1, pp. 115-213, https://hal.archives-ouvertes.fr/hal-00943740

[4] M. A. JOHNSON, P. NOBLE, L. M. RODRIGUES, K. ZUMBRUN. *Spectral stability of periodic wave trains of the Korteweg-de Vries/Kuramoto-Sivashinsky equation in the Korteweg-de Vries limit*, in "Transactions of the American Mathematical Society", 2015, vol. 367, pp. 2079-2135, https://hal.archives-ouvertes.fr/hal-00943738

Research Reports

[5] H. BARUCQ, M. BERGOT, J. CHABASSIER, E. ESTECAHANDY. *Derivation of high order absorbing boundary conditions for the Helmholtz equation in 2D*, Inria Bordeaux, November 2014, n^{o} RR-8632, https://hal.inria.fr/hal-01085180

Other Publications

[6] S. BOSCARINO, F. FILBET, G. RUSSO. *High order semi-implicit schemes for time dependent partial differential equations*, April 2014, https://hal.archives-ouvertes.fr/hal-00983924

[7] F. FILBET, L. PARESCHI, T. REY. *On steady-state preserving spectral methods for homogeneous Boltzmann equations*, August 2014, https://hal.inria.fr/hal-01053930

[8] F. FILBET, T. REY. *A hierarchy of hybrid numerical methods for multi-scale kinetic equations* , February 2014, https://hal.archives-ouvertes.fr/hal-00951980

[9] F. FILBET, C. YANG. *Mixed semi-Lagrangian/finite difference methods for plasma simulations*, September 2014, https://hal.inria.fr/hal-01068223