A propos du centre ou de la direction fonctionnelle

The Inria Rennes - Bretagne Atlantique Centre is one of Inria’s eight centres and has more than thirty research teams. The Inria Center is a major and recognized player in the field of digital sciences. It is at the heart of a rich R&D and innovation ecosystem: highly innovative PMEs, large industrial groups, competitiveness clusters, research and higher education partners, laboratories of excellence, technological research institutes, etc.

Mission confiée

The interaction of an ultrafast electromagnetic pulse with the electronic spins in a ferromagnetic nanostructure has been the object of intense investigations, both theoretical and experimental, over the past three decades.

The main effect that was observed is the quick loss of magnetization following the excitation by the laser pulse. Several mechanisms to explain this demagnetization have been proposed. However, the scenario is far from being elucidated and as metallic nanostructures have many potential technological applications (nanophotonics, biology, medicine applications, ...), it is of great importance to make some significative progress in this domain.

In order to describe this complex problem, which requires the modelling of a nonlinear quantum-relativistic system of many electrons, the IPCMS group recently developed an alternative approach based on Wigner’s phase-space representation of quantum mechanics.

In this formulation, the state of a quantum system is represented by a function of the phase-space variables plus time. In the classical limit, the Wigner solution converges to the solution of a Vlasov equation, well-known in plasma physics. If one retains the spin degrees of freedom, the phase space distribution function is no longer a scalar, but rather a $2 \times 2$ matrix. The corresponding spin-Vlasov equation (coupled to Maxwell’s equations) constitutes a mean-field semiclassical model where the electron orbital motion is treated classically, while the spin is a fully quantum variable.

One of the main challenges of this postdoctoral proposal lies in the mathematical analysis and the numerical approximation of the novel spin-Vlasov models recently derived in the literature. When developing new physics models, it is often important to show that they display a Hamiltonian structure -- indeed, most fundamental physics models possess this property, once dissipative and other phenomenological effects are neglected. Subsequently, it will be of great interest to identify their intrinsic geometric structure, which will pave the way towards the construction of structure-preserving numerical methods.
Such methods have been introduced recently (in particular by the MINGuS group) in the computational plasma community.

To design structure-preserving numerical methods, there exist essentially two strategies:

- The first one, introduced in the MINGuS group consists in first splitting the Hamiltonian (which is a time approximation) and then discretizing the phase-space.
- The second option, explored by the group from Max Planck Institute (Germany) follows exactly the inverse order: after a suitable phase-space semi-discretization, a system of ordinary differential equation that enjoys the Poisson structure can be obtained and discretized using symplectic time integrators.

Historically, two different approaches exist for the numerical solution of the phase-space Vlasov equations. Eulerian codes work by meshing the entire phase-space with a grid and then solving the Vlasov equation by various methods. Eulerian codes provide an accurate description in all regions of the phase-space, but their computational cost is high. In contrast, particle-in-cell (PIC) codes work by following the trajectories of a large number of particles, thus providing a statistical sampling of the distribution function. Their computational cost is lower, but they suffer from statistical noise particularly in regions of low density.

These two families of methods (Eulerian and PIC) will be explored in this project in combination with the structure-preserving numerical methods described above. This strategy proved successfully when applied to Hamiltonian systems and one of our goals is to extend and transfer this approach to the context of the spin-Vlasov models. To achieve this, we will have to face several challenges.

Indeed, even though Eulerian techniques are well-studied for standard plasmas, their application to spin-Vlasov models is not as simple, as the phase-space distribution function is now a 2 x 2 matrix. One consequence is that the model is not a pure transport model as in the scalar case, which has a deep consequence in terms of numerical methods, since the standard semi-Lagrangian method (which is the method of choice for Vlasov equations) can no longer be used. Hence, novel time-splitting techniques, based on the matrix structure of the spin-Vlasov model, should be devised to take into account this problem. Another important point will be the preservation of the invariants of the spin-Vlasov model (total energy, momentum, and magnetization) from a numerical point of view, which is a reliability guarantee of the method.

Finally, let us emphasize the fact that the models considered here are high-dimensional, nonlinear and multiscale and, as such, will require the use of parallel simulations.

In this respect, we shall benefit from the SeLaLib library developed in the MINGuS group, which includes many parallel numerical routines dedicated to the simulation of Vlasov type models.

**Principales activités**
The main activities will consist in

- Design numerical methods and develop programs
- Write reports and scientific articles
- Present the works’ progress to partners and to scientific audience in workshops or conferences

**Compétences**

Technical skills and level required: a sound knowledge of numerical analysis and development of numerical methods for solving PDEs; a concrete experience in numerical modeling for kinetic equations.

Languages: English
Avantages
- Subsidized meals
- Partial reimbursement of public transport costs
- Leave: 7 weeks of annual leave + 10 extra days off due to RTT
- Professional equipment available (videoconferencing, loan of computer equipment, etc.)
- Social, cultural and sports events and activities
- Access to vocational training
- Social security coverage

Rémunération
Monthly gross salary amounting to 2653 euros