Meshes for TONUS

TOkamak NUmerical Simulations

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Outlines

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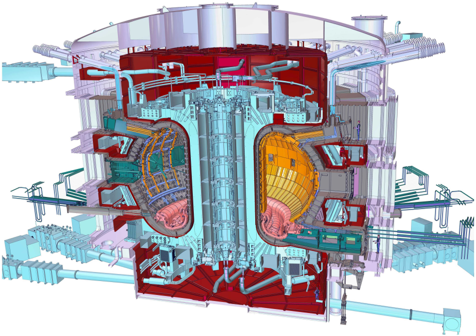
1) Tokamak

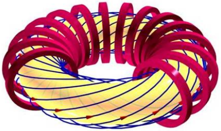
ITER project (I)

International Thermonuclear Experimental Reactor, ITER project: thermonuclear fusion in a hot hydrogen plasma (more than 100 millions of °C). Energy of the future.

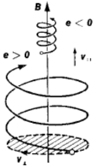


ITER project (II)

tokamak: magnetic plasma confinement in a torus. Poloidal coils $\Rightarrow$ toroidal field. Plasma current $\Rightarrow$ poloidal field $\Rightarrow$ plasma stability. Tamm-Sakharov in the 50's.



Strong magnetic field, few collisions: gyrokinetic turbulence.



Mathematical model

- Unknown: the distribution function $f(x, v, t)$. Number of ions at point x and time t having velocity v. The problem is time-dependent in a six-dimensional phase space.
- Vlasov equation with weak collisions

$$\partial_t f + v \cdot \nabla_x f + (E + v \times B) \cdot \nabla_v f = C(f) \simeq 0.$$

- Maxwell equations for the electric field E and the magnetic field B. Or Poisson equation on the electric potential Φ if the magnetic field is known

$$\nabla \cdot E = \rho - \rho_0, \quad E = -\nabla \Phi.$$

The charge ρ is given by

$$\rho(x, t) = \int_v f(x, v, t) dv.$$

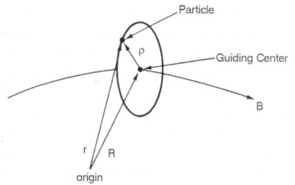
- Boundary conditions.

A challenge for numerical simulations

- Solving the full Vlasov-Maxwell model is too much expensive, even for supercomputers.
- Rigorous asymptotic simplifications.
- Adapted numerical schemes.
- Implementation in useful software.

Gyrokinetic modeling

In the gyrokinetic model, the Vlasov equation is replaced by a transport equation of the guiding centers.



The Poisson equation is replaced by the quasineutrality equation for the electric potential. Acting fields are obtained by gyroaveraging the real fields on the particles trajectories.
Much better results on aligned meshes.

Software: SeLaLib

- SeLaLib is an acronym for Semi-Lagrangian Library. It is supported by an Inria ADT [1]
- It is a collection of tools, written in Fortran 2003, for solving plasma physics problems.
- As of march 2013 it contains: high order semi-Lagrangian solvers, Poisson FFT-based solvers, parallel tools.
- The development is closely followed by our colleagues from CEA Cadarache. The SeLaLib modules will be used in the future versions of GYSELA.

[1] http://selalib.gforge.inria.fr/

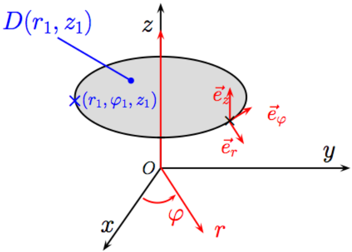
Software: CLAC

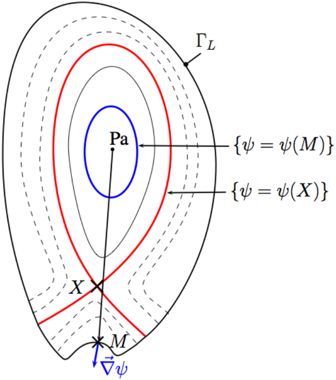
- CLAC is an acronym for Conservation Laws Approximation on many Cores.
- It is a generic 3D Discontinuous Galerkin (DG) solver for system of hyperbolic conservation laws: Maxwell, MHD, waterbags, reduced Vlasov, *etc.*
- It is based on OpenCL and MPI and thus runs on clusters of GPU's. It allows arbitrary order and non conforming meshes.
- It is developed with the company AxesSim in Strasbourg.
- Collaboration with the CAMUS team for multicore optimizations.
- It is being rewritten for better memory access.

Our meshes are structured, but...

- The tokamak core has a rather simple shape.
- The shape is given by an auxiliary computation (CASTOR team in Sophia, PlaTo ADT).

Magnetic configuration





Poloidal flux function $\psi(r,z)$.

$$B = B_p + B_\varphi, \quad B_p = \frac{1}{r}\nabla_{r,z}\psi \times e_\varphi, \quad B_\varphi = \frac{f(\psi)}{r} e_\varphi$$

$\Rightarrow$ "twisted" mesh, with a "cut".

High dimension

- we have to mesh a five or six-dimensional space
- (x, v) tensor product
- simple shape in v, but non-uniform is better.

$h-p$ adaptation

- the plasma behavior is different in the core and on the edge
- $X-$point
- numerical poloidal cut
- $h-p$ adaptation would give better results.

Related problems

- semi-lagrangian schemes: curved mesh transposition. Parallel data access problems.
- Particle-In-Cell methods: moving in parallel a huge number of particles.
- DG, Poisson solvers: more classical mesh topics.