How to simulate kinetic nonlinear effects in fusion plasmas.

Natalia Tronko[12], Alberto Bottino[1], Cristel Chandre[3], Dominique Escande[4] and Eric Sonnendruecker[12]

[1] Max Planck Institute for Plasma physics, Boltzmannstrasse 2, 85748 Garching,Germany
[2] Technical University of Munich, Department of Mathematics, Boltzmannstrasse 3, 85478, Garching, Germany
[3] Aix Marseille University, CNRS, Centrale Marseille, I2M, Marseille, France
[4] Aix-Marseille University, UMR 7345, Laboratory PIIM, avenue Escadrille Normandie-Niémen, 13397 Marseille
nataliat@ipp.mpg.de

Nonlinear phenomena are ubiquitous in fusion plasmas. They are especially important for understanding the transition towards the high confinement regime, which takes place in the outer *edge* region of the fusion device. In this region due to the strong nonlinearity, a transport barrier is created leading to confinement improvement. This nonlinearity is caused by the interactions between small and large scales requiring nonlinear kinetic turbulence simulations. Perhaps the direct simulations of the Maxwell-Vlasov equations would be a perfect tool for plasma behaviour prediction ; they still are unaffordable for nowadays supercomputers [1]. Therefore, the derivation and simulations of reduced kinetic models are required.

When the magnetic field is strong, it is natural to replace particles by their instantaneous centres of rotation around the magnetic field lines and therefore remove the fastest scale of rotation from the description of dynamics. It grounds the idea of the reduced kinetic (*gyrokinetic*) formalism. A multi-scaled Hamiltonian reduction procedure lies behind the construction of gyrokinetic dynamical reduction [2], [3].

It has been proved that the gyrokinetic models accurately predict violent, turbulent transport in the core region of a tokamak [4],[5]. However, understanding of processes in the *edge* of fusion devices, still be lacking. Several groups undertake the gyrokinetic simulations of the edge region across the world, i.e. [6],[7],[8]. However, the ordering used for the derivation of the core gyrokinetic models cannot be used for accurate modelling of the edge region. Indeed, concerning the core region, the simulations for the edge should include electromagnetic effects and be fully non-linear. There exist no gyrokinetic code nowadays, which possesses a model with these properties.

This talk will provide a pedagogical presentation of the principles of a unified theoretical framework for gyrokinetic models derivation suitable for code implementation. A historical introduction will show how mechanics made progress since Newton introducing more and more geometry.

Références

1. N. Tronko Noether method for magnetized plasmas, talk at Mathematical Sciences Research Institut, Berkeley, 2018 https ://www.msri.org/workshops/871/schedules/24664

2. N. Tronko and C. Chandre. Second order gyrokinetic theory : From the particle to the gyrocenter. *Journal of Plasma Physics*, 84 :925840301, June 2018

3. A. J. Brizard and T. S. Hahm. Foundations of nonlinear gyrokinetic theory. *Reviews of Modern Physics*, 79 :421, 2007.

4. A. Bottino and E. Sonnendrücker. Monte Carlo Particle-In-Cell methods for the simulation of the Vlasov-Maxwell gyrokinetic equations. *Journal of Plasma Physics*, 81(5) :435810501, 2015.

5. X. Garbet, Y. Idomura, L. Villard, and T. H. Watanabe. Gyrokinetic simulations of turbulent transport. *Nuclear Fusion*, 50 :043002, 2010.

6. D. R. Hatch et al., A gyrokinetic perspective on the JET-ILW pedestal , *Nucl. Fusion* 57, 036020 (2017). https ://doi.org/10.1088/1741-4326/aa51e1

7. Q. Pan and D. Told and F. Jenko Fully nonlinear delta-f gyrokinetics for scrape-off layer parallel transport *Physics of Plasmas* 23 :102302 (2016) ; https ://doi.org/10.1063/1.4964666

8. L. Villard and B. F. McMillan, E. Lanti et al Global and local turbulence features near and far from marginality and nonlocal pedestal-core interactions, to appear in PPCF 2019