Gyrokinetic simulations of turbulent transport

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A decisive step towards understanding of turbulent transport has been made with the development of the gyrokinetic framework for describing turbulence, and also with the emergence of numerical codes able to solve the set of gyrokinetic equations. This overview presents an assessment of the main advances in gyrokinetic theory and computing of turbulence.

This paper starts with a presentation of some basics in gyrokinetic theory. Solving 5D gyrokinetic Vlasov (or Fokker-Planck) equations for each species requires state-of-the-art High Performance Computing (HPC) techniques requiring massively parallel computers. Various numerical schemes have been explored until now, which can be classified as Lagrangian, Eulerian and semi-Lagrangian. Each approach has its advantages and drawbacks, which are summarised in this survey. The effect of geometry and the consequences of choices of locality versus globality are detailed. A particular attention is devoted to conservation properties and statistical convergence. Overall, it is certainly fair to say that gyrokinetics has triggered an activity in applied mathematics and computer science that extends well beyond plasma physics.

Some of the main results which have been brought by recent gyrokinetic simulations with regard to transport in fusion experiments are presented. In particular it is now well established that turbulence self-organises via the generation of structures which feed back on the turbulence background such as zonal flows, streamers, avalanches. Finally, one important aim of gyrokinetic theory is to predict turbulent transport in fusion plasmas. Toward this aim, validation is a central issue, and quantities such as turbulent fluxes, intensity and fluctuation spectra can be compared to experimental data whenever available. Also, the impact of dimensionless parameters such as the normalised gyroradius, plasma β, and collisionality has been extensively studied with the help of gyrokinetics and compared to the data coming from dedicated experiments.