Breaking new ground in magnetic fusion: stepping GYSELA towards exascale computing

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Context: Magnetic Fusion. Mastering thermonuclear energy is one of the great scientific adventures of today. It combines strategic political and social challenges with a major scientific problem that still pertains to the realm of fundamental research, especially through connection to the problem of turbulence and of the self-organisation of far-from-equilibrium systems. Progress is especially required in the basic understanding of turbulent transport to help offset risks when operating a future experiment as complex as Iter. The extreme temperatures require a first-principles so-called `gyro-kinetic' approach in which each species (ions and electrons) is described through a kinetic equation and coupled to Maxwell's equations.

The tool: the petascale gyrokinetic code GYSELA is one of the few representatives of a new class of approaches that has emerged (sometimes called `flux-driven'), describing the full distribution function for each species in realistic global geometries and with appropriate forcing and boundary conditions. Such approaches emphasise on the importance of self-organised processes that take place across scales: from machine size down to the microscopic sizes of turbulent eddies as well as organization at intermediate mesoscopic scales. Computations in such frameworks are challenging and require state-of-the-art high performance computing (HPC).

We will present here the numerical strategies and parallel optimizations that have been developed to increase the global performance of the code, preparing for future exascale simulations. We will also discuss key new physics that such an approach enables, especially emphasizing on three aspects: (i) unexpected synergies between transport channels with distinct spatiotemporal characteristics (collisional versus turbulent), (ii) the observation of spontaneous segregation of flows and avalanches, with deep analogies with geophysical fluid dynamics and (iii) the observation of distant interplay between regions often deemed as separated, necessary to understand the global self-organisation of turbulent fusion plasmas and to accessing regimes of enhanced confinement.