Numerical tools for the investigation of turbulence, instabilities, and flows in fusion plasmas

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Activities of EUROfusion's E-TASC TSVV Task 10 on burning plasmas will be presented. We describe theoretical models and numerical codes developed in our project. The focus of our activities is on the multi-scale nature of burning plasmas where the energetic particles couple together Alfvénic instabilities, turbulence, MHD phenomena, and transport. Numerical simulations carried out in our project are based on the global gyrokinetic approach which is a minimal inclusive description taking properly into account all the interlinked sub-systems of the burning plasmas. Since the global fully gyrokinetic simulations are computationally very expensive, development of reduced models is inevitable. We address this issue using hybrid fluid-particle global codes and developing integrated models formulated within the Energetic-Particle Workflow. We apply our numerical tools to various discharges featuring rich energetic-particle phenomenology. We perform global gyrokinetic simulations of electromagnetic turbulence using ORB5 and EUTERPE codes in presence of energetic particles and global MHD-like modes at different beta values in realistically shaped tokamak and stellarator geometries. First, different electromagnetic turbulence regimes (such as the Ion-Temperature-Gradient driven and the Kinetic-Ballooning-Mode regimes) have been addressed in our simulations for both tokamak and stellarator geometries. The next step was considering the multi-physics problems such as the interaction of the turbulence with the tearing instabilities and the non-adiabatic chirping dynamics of Toroidal Alfvén Eigenmodes (TAEs) in presence of the energetic particles. For the fluid and reduced modelling, successful XTOR-K simulations have been performed for the TAE modes destabilized by the energetic particles. Finally, the gyrokinetic eigenvalue code LIGKA has been evolved into an automated fully IMASified Energetic-Particle Workflow. This integrated framework has been implemented for discharge modeling in ASDEX-Upgrade, JT-60SA, JET, and TCV.