The role of zonal structures in burning plasmas

A. Biancalani[1], A. Bottino[2], M. V. Falessi[3], D. Gossard[4], T. Hayward-Schneider[2], P. Lauber[2], Z.X. Lu[2], A. Mishchenko[5], B. Rofman[6], J. N. Sama[7], L. Villard[6], X. Wang[2], F. Zonca[3,8]

[1] Léonard de Vinci Pôle Universitaire, Research Center, Paris La Défense, France, [2] Max Planck Institute for Plasma Physics, Garching, Germany, [3] Center for Nonlinear Plasma Science, ENEA, Fusion and Nuclear Safety Department, C. R. Frascati, Frascati (Rome), Italy, [4] École Supérieure d'Ingénieurs Léonard-de-Vinci, Paris La Defense, France, [5] Max Planck Institute for Plasma Physics, Greifswald, Germany, [6] Swiss Plasma Center, EPFL Lausanne, Switzerland, [7] Institut Jean Lamour, Université de Lorraine-CNRS, Nancy, France, [8] Institute for Fusion Theory and Simulation and School of Physics, Zhejiang University, Hangzhou, People's Republic of China

e-mail (speaker): alessandro.biancalani@devinci.fr

Tokamak plasmas have strong spatial gradients of density and temperature. Microinstabilities grow due to this gradients, and nonlinearly interact, forming turbulence. The turbulent transport is deleterious for the confinement of heat and particles in the tokamak core. Zonal (i.e. axisymmetric) structures (ZS) take an important role in the nonlinear saturation of turbulence [1,2,3,4]. Examples of ZS are zero frequency zonal flows and geodesic acoustic modes. Burning plasmas, i.e. regimes of plasmas expected in fusion reactors, are characterized by a substantial amount of highly energetic particles (EP) [5]. EP populations will be present due to fusion reactions, and in part due to external heating mechanisms. Although several models have been developed for the physics of turbulence in present tokamaks, the picture is still unclear about what will happen in burning plasmas.

In the recent years, the interaction of EPs and turbulence has taken a particular attention of the fusion community. In line with experimental measurements of turbulence mitigation in regimes with a relevant EP concentration [6,7], analytical models have been developed [8], and numerical simulations have been performed. Due to the technological limitations, flux tube simulations have been more affordable [9,10,11]. Yet, the selfconsistent interaction of microturbulence, mesoscopic ZS and macroscopic instabilities, has made the importance of global simulations clear, if one wants to address such an intrinsically multiscale problem [12,13,14,15,16,17].

In this work, we investigate the nonlinear dynamics of ZS in regimes of burning plasmas. The main theoretical tool is the global particle-in-cell code ORB5 [18], originally developed for electrostatic turbulence studies, and later on extended to its multispecies electromagnetic version. The effect of the EPs on the ZS will be shown, and the role of macroscopic instabilities as mediators will be considered. In particular, the effect of an EP population with temperatures typical of present tokamaks will be compared with an EP population with temperatures typical of burning plasmas. The consequences on the turbulence dynamics will also be discussed.

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