Large Scale Convective Structures and Instabilities in Edge Plasmas

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There is growing body of the experimental evidence that suggest that fast radial plasma transport in the tokamaks scrape-off layer is associated with large scale coherent structures (blobs) that separate from the main plasma and move radially outward. These structures with relatively small cross-field dimensions and extended along the magnetic field have plasma density that significantly exceeds the background plasma density in the scrape-off layer. Similar structures have also been observed in other devices, such as linear plasma machines. It was suggested earlier [1] that the blob motion is a specific form of plasma convection due to the electric field resulting from strongly non-uniform plasma polarization in the edge region. In this work we discuss basic mechanisms of plasma polarization and determine characteristic parameters of associated large scale convective structures. In general, plasma polarization can be caused by the plasma pressure force in the inhomogenous magnetic field [1], by the inertial force (polarization current) due to the time evolution and non-uniformity of the transverse flows [3], or by the action of the external forces such as neutral wind pressure [2]. For a uniform temperature case, the sheath effects have important stabilizing influence thus limiting the size of the structures, however for $\nabla T \neq 0$ they may provide additional destabilizing effects. We find that the magnetic field line bending seriously constrains the transverse blob motion, however fast electron thermal motion along the magnetic field lines largely removes it because the magnetic field becomes frozen into the electron component while the ion (mass) flow is decoupled from the magnetic field. A small residual non-divergent-free part of the difference between the transverse ion and electron velocities determines the parameters of the polarization field. We have also analyzed the possibility of the self-polarization of large scale structures due to the small-scale instabilities via the Reynolds stress mechanism. The development of the secondary, small scale instabilities at the blob-background plasma interface appears to be a further selection mechanism limiting the maximal size of the convective structures. Nonlinear simulations of these instabilities [4] show that large scale blobs disintegrate via sequence of states similar to the nonlinear stages of the Raleigh-Taylor instability in an unstably stratified fluid.

It is expected that the convective blob structures are also strongly inhomogeneous in the axial direction (along the magnetic field). We show that these configurations are subject to the robust axial shear instability. This electromagnetic instability has a significant growth rate (of the order of the characteristic transverse convective frequency, V/δ, where is the convective velocity and δ is the characteristic length scale across the magnetic field. The further, nonlinear evolution occurring on a longer, ion sound time scale, leads to the redistribution of the plasma density within the blob.

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