Theory of Rapid Transport by 3D Blobs*

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There has been a great deal of recent work on the theory of SOL transport by coherent density structures called "blobs" [1,2]. This work is motivated by experimental observations of high-density structures aligned parallel to the magnetic field but very localized perpendicular to the field. Diagnostics on tokamaks and on linear experiments show that these structures move radially outwards contributing to the intermittent transport measured in the SOL. A recent review [3] of 2D blob theory and its experimental motivation shows that the simple theory provides a robust mechanism for radial transport in the presence of an outward force (curvature, centrifugal, or neutral wind) and has several points of qualitative agreement with experiments and turbulence simulations. The 2D theory assumes no variation along the field lines and good connection of the blobs to the sheaths, so that the blob charge polarization is limited by parallel current flow into the sheaths. Subsequently, 3D turbulence simulations with neutral sources were carried out for DIII-D plasmas near the density limit [4], and preliminary analysis [5] of the simulation results showed that blobs were produced by the turbulence with some of the features expected from the simple 2D theory. Further analysis [6] of the 3D high-density simulation showed that in fact the radial blob velocity exceeds that predicted by the 2D sheath-connected blob model, and the temperature has a dipole structure, neither of which can be explained by the earlier theory. Moreover, this simulation is in the regime where the turbulence and the coherent structures acquire a ballooning structure along the field lines making the physics essentially three dimensional. In a separate study, it has been shown that the degree to which the blob is electrically connected to the sheath influences its rotation and many aspects of its dynamics [7].

These results point to the need for a 3D theory of blob transport which takes into account the details of parallel connection along the field line, especially of the currents induced by the blob. Here, a first attempt at such a theory will be discussed. It is shown that a combination of the curvature and thermoelectric terms in Braginskii theory permit a 3D blob solution in which the parallel currents are converted to perpendicular currents near an X-point [8] in such a way as to support a temperature dipole (along with the usual dipole charge and vorticity) in the blob. The induced potential and resulting outwards $\mathbf{E}\times\mathbf{B}$ drift are much larger for the 3D solution than for 2D model. Both of these features agree qualitatively with the 3D simulations [6]. The scaling of three mechanisms for perpendicular current generation (collisional electron conductivity, ion viscosity, and ion polarization current) will be compared and the dominant one in the simulation [4] will be identified. Finally, the scaling of the 3D blob velocity with plasma parameters will also be examined to see if this mechanism could play a role in the density limit.

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