Blob Transport Models and Analysis of 2D Imaging Experiments

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The importance of intermittent, convective transport of plasma in the scrape-off-layer (SOL) of fusion devices is by now widely recognized. Transport models based on the "blob" paradigm [1] provide a useful conceptual framework. Recent work, described here, allows a unified picture of curvature driven edge instabilities and blob transport regimes in a tokamak to be formulated and enables testable predictions for the magnitude and scaling of the radial convective velocity v_x of a given blob. Because radial transport, governed by v_x, competes with classical parallel transport of particles and energy along the field line, understanding the physics of v_x is critical to determining the radial penetration of plasma into the far SOL (convective) zone.

Coherent structures have long been observed in edge turbulence. However, the advent of modern fast-time-scale high-spatial-resolution imaging techniques, presents a new opportunity for the comparison of theoretical models with data. In this paper we consider the use of Gas Puff Imaging (GPI) experiments described elsewhere [2]. New results on the modeling of GPI experiments are given. Finally, we report on the analysis of the observed blob velocity, and its interpretation in term of blob models.

Blob Transport Regimes and Models – A filamentary structure (blob) in the SOL is subject to e/i charge separation from curvature and grad-B drifts. [1] This current source drives electrical current loops that can flow along the field lines and terminate in sheaths (sheath-connected case), or in the opposite extreme, close locally by cross-field ion polarization drifts (disconnected). [3] In intermediate cases, current loop closure is facilitated at X-points by the flux tube fanning. [4] The physics of parallel disconnection can be modeled in 2D simulations using a two-region model which couples two planes (⊥ to B) by field line mapping and continuity equations for density and charge. Analytical analysis and numerical simulation confirm the existence of dimensionless blob regimes in this model, characterized by collisionality, $\Lambda = \nu_{ei}L_{||}/\Omega_e\rho_s$ and dimensionless blob size $\hat{a} = a_b / a_* = L_{||}^{2/5}(2\rho_s R)^{-1/5}$ (Fig. 1), each with specific v_x scalings. The NSTX data described below is marginally in the sheath-connected regime [1] where $v_x = c_s\, q\, (\rho_s/a_b)^2$.

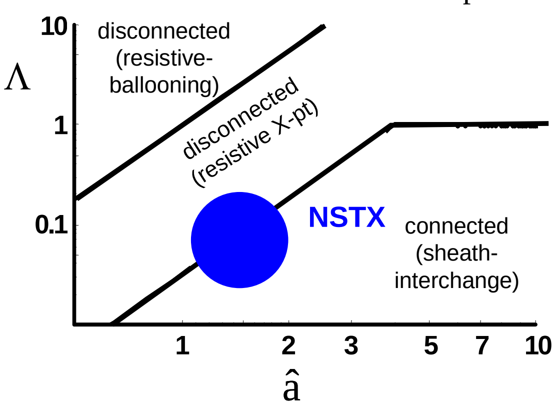

Fig. 1 Regimes of blob propagation

Modeling of Gas Puff Imaging (GPI) Experiments – GPI employs photons generated by electron impact excitation of gas puffed near the plasma edge to visualize and record turbulence. Because the diagnostic measures emission rather than plasma density or temperature, analysis has been performed to test the interpretation of the data.

Previous work [5] has shown that the spatial structure of the emission reflects that of the underlying plasma parameters. Here the temporal variation of the system is examined in an analogous manner since the atomic physics processes upon which GPI is based are not instantaneous. We find that the familiar single state collisional radiative CR model for helium is able to resolve time variations slower than 1 μs and is, thus, suitable for present GPI experiments.

This single state model yields a simple relationship between the plasma parameters, n_e and T_e, and the observed light emission, $S = n_0F(n_e, T_e)$, where n_0 is the helium ground state density and the function F is provided by the CR model. If n_0 can be estimated, and n_e can be related to T_e, the spatial and temporal variation of the plasma parameters can be unfolded from the GPI images. Tests of this procedure will be reported. It is found that simulated and time-averaged emission clouds have the same spatial orientation and peak location to within the estimated errors, however agreement is not perfect, e.g., the simulated emission clouds are narrower than those observed.

Analysis of blob birth and transport from GPI Data – Analysis of GPI "movies" taken using a He gas puff in D plasma have been used to create a database of blob parameters: birth zone, blob scale size a_b, v_x and (using the single state model to infer plasma density and temperature from the He 5876 emission), density and temperature. Measured properties were compared with theory for a small subset of bright, long-lived, isolated blobs for which relatively accurate v_x determinations could be made. Making the ansatz that the blobs convect density and temperature together [i.e. $T_e = T_e(n_e)$] over short distances from the blob birth zone, several conclusion could be made. (i) The blob birth zone is near the local maximum of the edge $\nabla\, ln$ <p> suggesting blob generation by an underlying edge instability. (ii) The observed v_x are equal to, or exceed, a minimum blob velocity appropriate to their location on the regime diagram, viz. the sheath-connected regime. The excess depends on position and is qualitatively consistent with separatrix and parallel "disconnection" effects. However, some additional physics not in the present model also influences v_x. A similar maximal (resistive ballooning) bound is also seen.

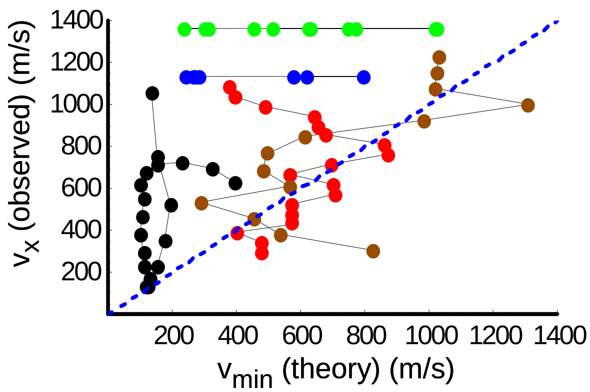

Fig. 2 The observed blob velocity is bounded by a theoretically predicted minimum.

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[1] S. I. Krasheninnikov, Phys. Letters A, **283**, 368 (2001); D. A. D'Ippolito, J. R. Myra and S. I. Krasheninnikov, Phys. Plasmas **9**, 222 (2002).
[2] R. Maqueda, *et al.*, this conference; and refs. therein.
[3] J.R. Myra and D. A. D'Ippolito, Phys. Plasmas **12**, 092511 (2005).
[4] S. I. Krasheninnikov, D. D. Ryutov, and G. Q. Yu, J. Plasma Fusion Res. **6**, 139 (2005).
[5] D. P. Stotler et al., Contrib. Plasma Phys. **44** (2004) 294.