Gyrokinetic study of edge blobs and divertor heat-load footprint

C.S. Chang[1], J. Boedo[2], R. Hager[1], S. Ku[1], J. Lang[1], R. Maingi[1], D. Stotler[1], S. Zweben[1]
[1]Princeton Plasma Physics Laboratory, Princeton, NJ
[2]University of California, San Diego, CA
cschang@pppl.gov

Even though the physics leading to the divertor heat-load footprint and the nonlinear "blobby" turbulence or "intermittent plasma objects" are critically important issues for ITER [1], they have only been studied using simplified models or fluid equations with ad hoc kinetic closures based upon Maxwellian ansatz. Edge plasma is not in a thermal equilibrium state. For more complete understanding and predictability, it requires a fully kinetic treatment in realistic diverted geometry with sources and sinks. Blobs and heat-load footprint should be studied together since they may be coupled. Neoclassical and turbulence physics should also be studied together since they interact strongly in the edge plasma. In order to understand this complicated physics, the full-function gyrokinetic PIC code XGC1 has been used in realistic diverted geometry; including gyrokinetic ions, drift kinetic electrons, Monte Carlo neutrals with wall-recycling, heat and torque source in the central core, fully nonlinear Fokker-Planck collisions, and logical Debye sheath boundary. The ~20 petaflop computer, Titan, at ORNL has been used at its near full capability with total ~100 billion marker particles. Blobs are modeled here as electrostatic nonlinear turbulence phenomenon.

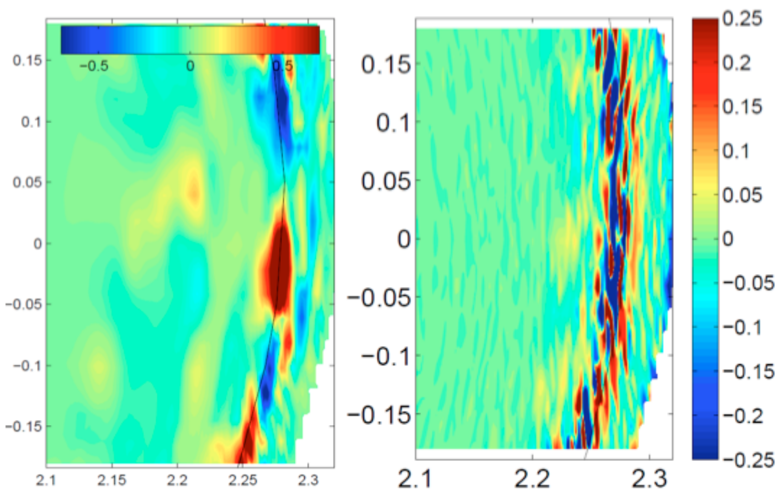

Figure 1. (left) Normal type blobs and (right) H-mode type blobs in DIII-D geometry. The H-mode blobs may be better described as "intermittent plasma objects" since their size is limited in the major radial direction by stronger ExB shearing rate with median width of ~1cm.

It is found that the "blobs" are generated, together with the "holes," around the steep density gradient region at low magnetic field side (Figure 1). We note here that a steep density gradient usually exists just inside the magnetic separatrix surface in both L- and H-mode edge we have modeled, with greater pedestal height and width in an H-mode edge. Blobs move out convectively into the scrape-off layer, carrying plasma density and energy with them, while the holes move inward toward plasma core, as known previously. The blob/hole generation, shape and dynamics are correlated with the poloidal E_rxB flow shearing rate.

In an H-mode plasma, in which the heat-load width is of concern, the "blobs" are found to be different in both shape and dynamics from L-mode blobs. In a DIII-D H-mode-like plasma with B_0=2T, in which the E_rxB shearing rate is high, the median radial size of the density blobs in the scrape-off layer is only about 1 cm with their structure severely elongated in the vertical direction (see Fig. 1). The conventional type large isotropic "blobs" occur only at the tail of PDF. While the blobs move out radially, they are carried toward the outer divertor plate by ExB flow at a much faster speed ($V_{ExB} >> V_r$) in H-mode. Their poloidal speed is similar to experiment experimental data [2].

Figure 2 shows the electron and ion heat-load footprint on outer divertor plates of DIII-D tokamak. It can be seen that the heat-load is highly concentrated near the separatrix leg, and that the ion heat-load width is wider than that of electrons, which indicates that there are differentiating mechanisms. As a matter of fact, the measured radial width of the total heat load, mapped back to the outer midplane, is only ≈0.4 cm. This width is much less than the median radial size of the blobs, but closer to the banana width of the ions at outer midplane. This result indicates that the warmer particles not well trapped inside the blobs, but outruns the blobs along the magnetic field direction toward the divertor plates. This result also shows that the radially outward motion of the blobs does not contribute to the radial spreading of the heat-load footprint, indicating that blobs may not actually hit the divertor plates even if they appear to flow toward them. Movie of the blob dynamics actually shows that the blobs execute a large scale convective motion along the divertor plates, instead of hitting them, as they approach the plates. Figure 3 shows the poloidal variation of the electrostatic potential at several separatrix surfaces in the scrape-off layer. It can be seen there exists strong pre-sheath in front of the divertor plates. Strong pre-sheath gives fast $E_w xB$ motion along the plates, where E_w is the pre-sheath electric field normal to the divertor plates, preventing them from hitting the plates. The blobs eventually move back convectively toward the midplane at far-scrape-off region, while their energy dissipates. Comprehensive experimental validation is part of the study.

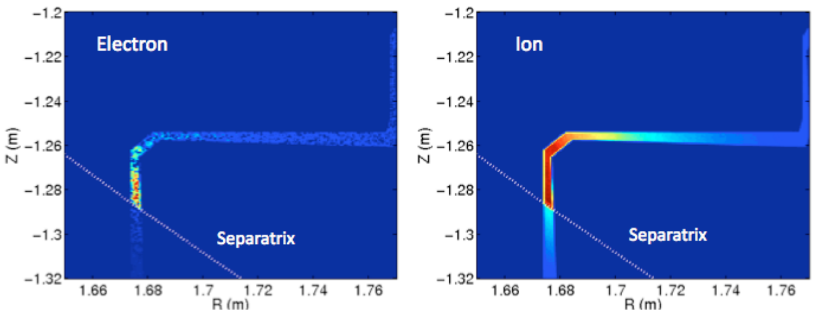

Figure 2: Heat flux footprint on the outer divertor plates of DIII-D tokamak in an H-mode like edge plasma.

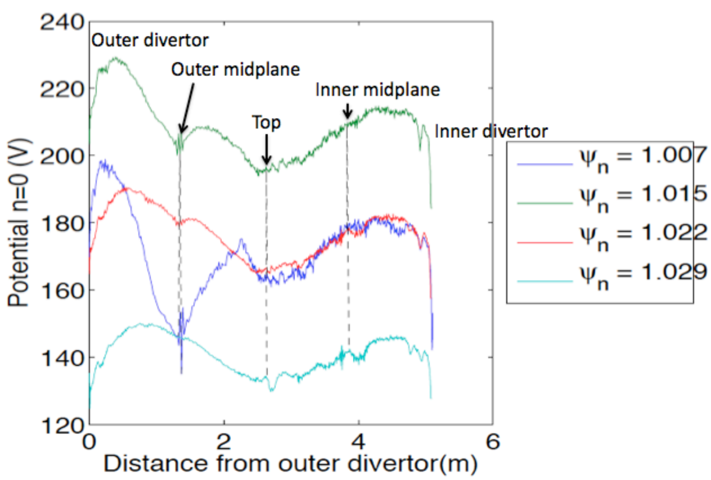

Figure 3: Electrostatic potential variation along magnetic field line at different Ψ_N surface.

[1] D. D'Ippolito et al., Phys. Plasmas 18 (2011) 060501
[2] J. Boedo et al. Phys. Plasmas 10 (2003) 1670