Final Report

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"Edge, Sol, and Diverter Plasma Turbulence and Macroscopic Transport"

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Summary

In the last few years, it was clearly shown that cross-field transport in the far SOL could be significantly faster than previously thought and that this transport exhibited convective rather then diffusive features. As a result, in high density cases the plasma coming into the SOL from the core recycled at the wall of the tokamak main chamber, rather than flowing into the divertor and recycling there, as the conventional picture of edge plasma flows would suggest. It was also shown that coherent structures, often called "blobs", played very important roles in the particle and energy transport inside the SOL region for both L and H confinement modes. The blobs seen in the SOL are extended along the magnetic field lines and have a plasma density two to three times higher than the ambient SOL plasma density and poloidal and radial scales of about 1 cm. In experimental measurements, the blobs propagated in radial direction towards the chamber wall with a velocity $\sim 10^5$ cm/s, and the contribution of non-diffusive flux associated with transport of blobs to the total particle flux in the far SOL attained 70-90%. In addition, recent assessment of experimental data and theoretical models shows that plasma propagation into the SOL during ELM is somewhat similar to that of blobs.

Interestingly, similar features of plasma turbulence were observed in stellarators and linear-plasma devices. In linear devices, it was found that cross-field plasma transport in the "SOL" region (the region where magnetic field lines are not connected to the plasma source) was very intermittent and that plasma blobs propagating radially to the wall with velocity $\sim 10^5$ cm/s were the main contributors to plasma particle flux. Moreover, comparison between intermittent transport properties measured on the PISCES linear device and on several tokamaks (namely, Alcator C-Mod, MAST, and Tor-Supra) showed almost identical power spectra and probability distribution functions of ion saturation current fluctuations in the SOL regions of these devices.

All these findings on various fusion devices show that we are dealing with fundamental property of cross-field plasma transport. They significantly alter our understanding of edge plasma transport, recycling, impurity sources and transport, and plasma-wall interaction. They can result in the far-reaching consequences for the design of future fusion devices and, therefore, should be understood in detail. In addition, these findings are also of general theoretical interest (e.g. how blobs are related to the qualitative physical picture of anomalous transport outlined above).

In trying to assess the issues of intermittent anomalous plasma transport, many questions immediately arise: what are the physical mechanisms causing blob propagation in the SOL; how stable are the blobs; how far can a blob penetrate into the SOL; what determines the percentage of particle and energy flux that blobs carry away; what is the role of neutrals and ambient SOL plasma in the particle and energy transport *per se* as well as in the blob dynamics; how can intermittent anomalous transport with large contribution from convective structures be incorporated into macroscopic 2D transport codes (e. g. UEDGE code) to perform integrated studies of the edge,

SOL, and divertor plasmas; and how the non-diffusive component of anomalous transport depends on global discharge plasma parameters and under what conditions does it dominate? We have suggested that blob motion in tokamak SOL might be caused by the ∇B and curvature drifts of charged particles in the curved magnetic field of a tokamak and that these drifts resulted in plasma polarization and, correspondingly, in the **E**×**B** radial convection of the blob plasma. The **E**×**B** flow became rather strong in the SOL due to the effective "sheath resistivity" when the plasma contacted the divertor target. The estimates of blob radial velocity in were in agreement with experimental data. Further analytical and numerical investigations of this idea have shown, that while large blobs are subject to fingering effects caused by the flute instability, relatively small blobs (~1cm) can move coherently over large distances (~10 cm). In linear devices the ∇B and curvature drifts can be substituted by the "neutral wind" effects.

To understand the role of non-diffusive features of anomalous cross-field transport in the integrated simulation of the tokamak edge, SOL, and divertor plasmas, a hybrid, diffusive and convective, plasma transport model was applied within the framework of the 2D transport code UEDGE. The non-diffusive transport was modeled macroscopically with the 2D transport code UEDGE by using hybrid, diffusive and convective, plasma transport model. In a series of UEDGE runs, the cross-field convective velocity V_{conv} profile, along with plasma diffusivities, was adjusted to match representative set of experimental data. We found that the pure diffusive and the hybrid (diffusive and convective) models were both well capable of fitting the few main parameters such as SOL plasma density and temperature profiles in the narrow region adjacent to the separatrix. However, the pure diffusive model failed to properly describe plasma transport in the far SOL with physically meaningful magnitude of diffusion coefficients. At the same time, the hybrid model was able to match most of relevant experimental data in the L mode shot and between ELMs in the H mode shot.

In high-density C-Mod discharges, the fast SOL transport lead to the main-chamber recycling regime, in which the core plasma was fueled predominantly due to neutrals originating from the chamber wall. The transition from the regime, in which the core plasma was fueled due to the leakage of neutrals from the divertor, to the main chamber recycling regime with an increase in the discharge density was found with UEDGE modeling of a series of L-mode DIII-D shots that provided the edge density scan at the same power input. In addition, the non-diffusive cross-field plasma transport in the SOL affected not only the mid-plane plasma parameters but also the parameters in the divertor region by decreasing the peak load on divertor plates in the radiative divertor shot. This implies that the divertor detachment process can be strongly altered by the blobby plasma transport in the SOL.

The results of our studies were published in 29 refereed publications (see attached list).

Abstract
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We have developed the model of blob motion in tokamak SOL caused by the grad(B) and curvature drifts of charged particles in the curved magnetic field of a tokamak and that these drifts resulted in plasma polarization and, correspondingly, in the ExB radial convection of the blob plasma. The ExB flow became rather strong in the SOL due to the effective "sheath resistivity" when the plasma contacted the divertor target. The estimates of blob radial velocity in were in agreement with experimental data. In linear devices the grad(B) and curvature drifts can be substituted by the "neutral wind" effects. To understand the role of non-diffusive features of anomalous cross-field transport in the integrated simulation of the tokamak edge, SOL, and divertor plasmas, a hybrid, diffusive and convective, plasma transport model was developed and applied within the framework of the 2D transport code UEDGE. We found that the pure diffusive model failed to properly describe plasma transport in the far SOL with physically meaningful magnitude of diffusion coefficients. At the same time, the hybrid model was able to match most of relevant experimental data in the L mode shot and between ELMs in the H mode shot.

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