Edge and divertor plasma: detachment, stability, and plasma-wall interactions

S. I. Krasheninnikov[1]†, A. S. Kukushkin[2,3], Wonjae Lee[1], A. A. Phsenov[2,3], R. D. Smirnov[1], A. I. Smolyakov[4], A. A. Stepanenko[3], and Yanzeng Zhang[1]

[1]University of California San Diego, La Jolla, CA 92093, USA; [2]Kurchatov Institute, Kurchatov sq. 1, 123182 Moscow, Russia; [3]NRNU MEPhI, Kashirskoje av. 31, 115409 Moscow, Russia; [4]University of Saskatchewan, 116 Science Place, Saskatoon, SK S7N 5E2, Canada

Physics of divertor detachment

The results of thorough 2D simulation of edge plasma with SOLPS code (Krasheninnikov et al., PoP, 2016) confirm theoretical predictions that impurity radiation loss and plasma recombination are the main reasons of the rollover of plasma flux to divertor targets in the course of divertor plasma detachment (Krasheninnikov, CPP, 1996; PoP, 1997). Although ion-neutral interactions are important for maintaining appropriate upstream and divertor plasma parameters, they are not responsible *per se* for the reduction of plasma flux to the targets (see Fig. 1).

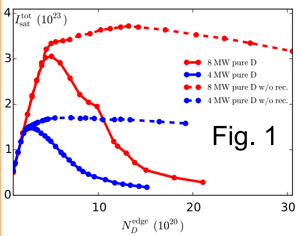

Fig. 1

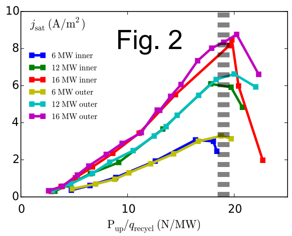

Fig. 2

2D simulations also confirm that the condition governing an onset of the rollover of plasma flux to the target at some particular flux tube can be written as $P_{up}/q_{recycl} \gtrsim (P_{up}/q_{recycl})_{crit}$ where P_{up} and q_{recycl} are the upstream plasma pressure and the heat flux to recycling region (Krasheninnikov, et al., JNM, 1999) (see Fig. 2). Impurity driven local thermal instabilities in ITER-like plasma can cause significant (~50%) variation of the heat load on divertor target (Fig. 3) Smirnov, et al., PoP, 2016

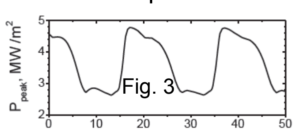

Fig. 3

Generation of blobs and dynamics of drift waves

Blobs play a crucial role in the Scrape-Off-Layer plasma transport. However, there is compelling experimental evidence that high density plasma blobs exist already inside separatrix where they are moving predominantly in poloidal direction. In (Krasheninnikov, PLA, 2016) it was shown that by retaining a non-linear Boltzmann factor in Hasegawa-Mima equation

$$de^{\phi}/dt - \rho_s^2 \nabla\cdot(e^{\phi} d\nabla\phi/dt) + V_{DW} e^{\phi} \vec{e}_x \cdot (\nabla\phi \times \vec{b}) = 0$$

one can find solution of a large amplitude n/n_0~3 virtually solitary drift waves moving in poloidal direction. Numerical simulations show that such large bursts of density can emerge even from initial perturbations of small amplitude (Zhang & Krasheninnikov, submitted).

Current-conv. Inst. in detached plasmas

In (Krasheninnikov & Smolyakov, PoP, 2016) it was shown that Current-Convective Instability (CCI), which for a tokamak condition is usually stabilized by high parallel electron heat conduction can develop in cold detached plasmas for the conditions where inner divertor is detached while outer is still attached. For this case asymmetry of plasma temperatures near the targets causes a large drop of electrostatic potential within cold inner divertor, which drives electric current and CCI. Once outer divertor detaches CCI is no more. These findings can explain the AUG data on radiation fluctuations from inner divertor (Potzel, et al., NF, 2014).

Formation of the layer of Helium nano-bubbles in Tungsten

Due to its low solubility He tends to precipitate into bubbles when embedded into metals. For a sample temperature below 1000 K, the layer of He nano-bubbles of the thickness ~30-50 nm and diameter ~ 2 nm was observed experimentally in the near-surface region of He irradiated tungsten, for He energies below the sputtering threshold and fluxes relevant to the ITER conditions (e.g. Kajita, et al., NF, 2009). This layer saturates at He fluence ~3×10^{20} cm^{-2} regardless the magnitude of He flux. However, the MD simulations of the formation of He nano-bubbles accounting only for self-trapping of He atoms were unable to fit these experimental observations. In (Krasheninnikov & Smirnov, NF, 2015) it was shown that each growing He nano-bubble produces dislocations in W lattice, which can effectively trap He atoms and can work as the seeds of new nano-bubbles. In Fig. 4 one can see MD simulation results for He clusters formed due to trapping in these dislocations and due to He self-trapping. The reaction-diffusion model describing dynamics of free He and He clusters, which takes into account the generation of traps associated with growing nano-bubbles, allowed to match most crucial experimental data (critical He fluence, thickness of the layer, and bubble diameter).

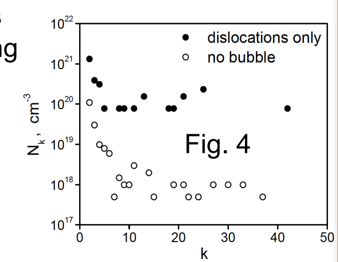

Fig. 4