Particle-In-Cell simulation of parallel blob dynamics in near scrape-off-layer plasma of medium-size tokamak

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Blob transport is subject to intense study in fusion energy research for the understanding and prediction of particle and heat fluxes onto the plasma-facing components (PFC) [1]. These structures originate around the separatrix at the outer midplane, forming filaments which expand and propagate in the parallel and, respectively, perpendicular (outwards) direction, with respect to the total magnetic field. Although considerable work has been done to address the perpendicular (radial and poloidal) transport in the scrape-off-layer (SOL) plasma, both experimentally and numerically, the dynamics of these filaments along the flux tube did not receive sufficient investigative attention. Up to now, flux tube dynamics simulations assumed constant temperatures, forced Maxwellian-distributed species and/or no divertor physics. Experimentally, mean parallel flows can only be estimated by using Mach probes [2].

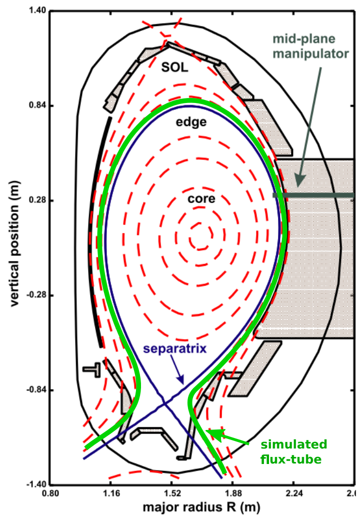

Figure 1: *Cross-section of magnetic configuration of a diverted medium-size tokamak. Green line: the investigated magnetic field line.*

This work aims to study the dynamics of a blob crossing a magnetic field line in the near SOL (Figure 1, green line) and its influence in terms of heat and particle flux along the magnetic field line, up to the inner and outer divertors, in deuterium plasma. Emphasis is given on the first phase of the blob – the transport of the blob's hot electrons to the divertor.

The simulation is done in two steps: first, a steady-state plasma is reached, with realistic plasma profiles in the parallel direction; on top of it, a blob with given density and temperature is superimposed at the outer midplane, as shown in

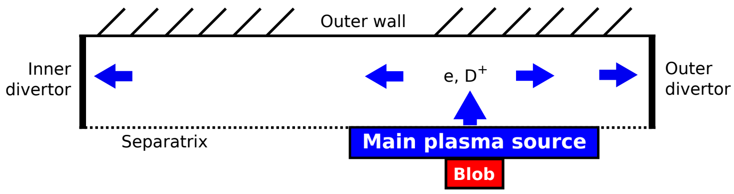

Figure 2: *BIT1 simulation geometry.*

Figure 2, and the corresponding transport is studied. The model takes into account electron and ion temperature fluctuations, as well as non-Maxwellian velocity distributions. The numerical simulations are performed via BIT1 code [3] and the simulated plasma parameters are relevant to the SOL of medium-size tokamaks (MST).

In Figure 3, we observe that the hot electrons of the blob leave their initial position at the outboard midplane much faster than the hot ions, creating a local positive potential perturbation. This potential perturbation produces an electric field which attracts the electrons and repels the ions of the background plasma, restoring the quasineutrality of the plasma (see the total electron and ion densities, green curves).

Even if the blob enters the investigated magnetic field line at the midplane, we observe in our simulations that its hot electrons can reach the divertors (see Figure 4), for the lower plasma density cases investigated. The time for the hot electrons of a blob to reach the two divertors can be identified in Figure 5 by the maximum in the timetrace of the blob's electron energy flux (red curves), where t=0 s represents the activation of the blob's source at the outer midplane. We also observe that the transition between single and bi-Maxwellian EEDFs at the two divertors takes place in a narrow range of the main plasma density in the SOL, i.e. when the density varies around 2-3 times (Table 2), comparable to experimental findings [4].

The ion energy fluxes at the divertors (black curves) increase by 50% when the hot electrons of the blob arrive. This coincides with the maximum potential drop between the midplane and each of the divertors, which increases the ion acceleration towards the two divertors.

Table 1: *The simulated plasma cases. The values refer to the densities (n) at the outer midplane before (left column) and at the end (right column) of the blob injection and the source temperatures (T) for the main plasma source and the blob source.*

Main-plasma source			Blob source		
n [10^{18}m^{-3}]	T_e [eV]	T_i [eV]	n [10^{18}m^{-3}]	T_e [eV]	T_i [eV]
1			5		
2	10	20	11	50	50
3			16		
7			35		

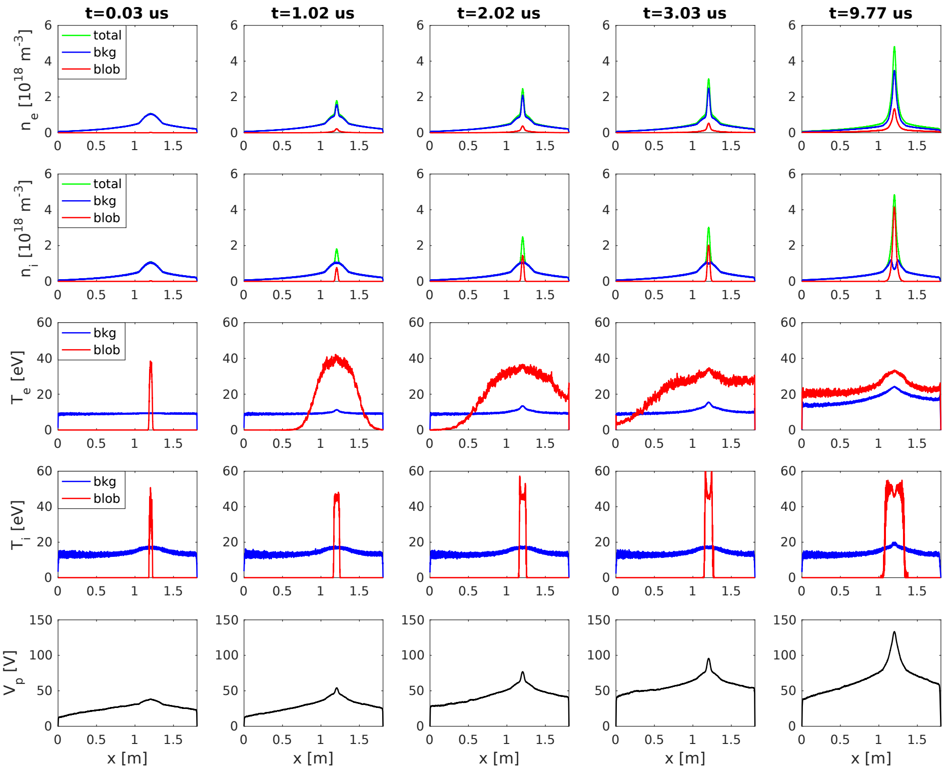

Figure 3: *BIT1 simulation of a flux tube close to separatrix in the SOL plasma (blue curves) of a MST and a blob crossing it (red curves) at the outer midplane (x=1,2 m). Poloidal profiles of plasma potential (V_p), (e)lectron and (i)on densities (n) and temperatures (T) are presented for different moments in time since the activation of the blob's source. The blob source was active for 10 μs, to emulate a radial transition time across the flux tube at the midplane. The total density is represented by the green curve.*

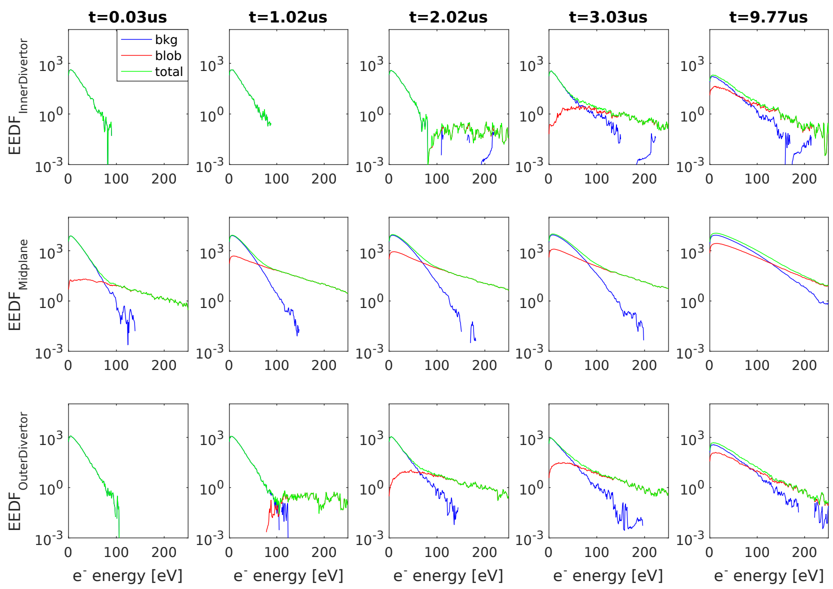

Figure 4: *Evolution of the electron energy distribution functions (EEDFs) at the position of the inner divertor, midplane and the outer divertor, for $n = 1 \cdot 10^{18} m^{-3}$. The blue curve represents the main (background) plasma, the red curve represents the blob and the green curve represents the total plasma.*

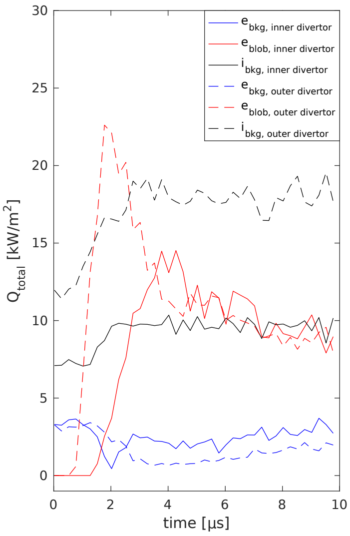

Figure 5: *Energy fluxes of electrons coming from the steady-state plasma (bkg, solid/dashed blue), of electrons from the filament (blob, solid/dashed red) and of ions from the steady-state plasma (bkg, solid/dashed black) to the inner (solid line) and outer (dashed line) divertors. t=0 s represents the activation of the blob's source at the outer midplane.*

Table 2: *Occurrence of non-Maxwellian EEDFs at the divertors vs. SOL plasma density, during a blob crossing the midplane.*

	Electron Energy Distribution Function (EEDF)			
n [10^{18}m^{-3}]	Inner divertor	Midplane	Outer divertor	Legend
1	b	b	b	s = single
2	b	b	b	Maxwellian
3	s	b	b	b = bi-
7	s	b	s	Maxwellian

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