INFLUENCE OF ION TEMPERATURE ON THE DYNAMICS OF UNIDIRECTIONAL CURRENT CARRYING FILAMENTARY ELM BLOBS IN THE EDGE REGION OF A TOKAMAK

[1,3,a)]SOUVIK MONDAL, [1,3]N BISAI, [1,3]ABHIJIT SEN, [1,2,3]INDRANIL BANDYOPADHYAY

[1]Institute for Plasma Research, Bhat, Gandhinagar 382428, Gujarat, India
[2]ITER-India, Institute for Plasma Research, Bhat, Gandhinagar 382428, Gujarat, India
[3]Homi Bhabha National Institute, Training School Complex, Anushaktinagar, Mumbai 40094, India

[a)]Email: souvik.mondal@ipr.res.in

The tokamak edge region is known to be highly turbulent that gives rise to an intermittent convective type of transport. The anomalous nature of the transport is attributed to the formation and movement of coherent high-density filamentary structures - also known as “blob” [1, 2]. These blobs arise from the differential stretching and shearing of turbulence-generated nonlinear elongated structures called streamers and have been the subject of many past studies. Blobs can also arise as ejection events of Type-I, II, and III Edge Localized Modes (ELMs) [3, 4]. These blobs are characterized by a coherent unidirectional current extending along the direction of the magnetic field [5, 6] and are different from the conventional blobs arising from the breakup of streamers. They are polarized by the curvature drifts that generate a self-driven radial motion and two such blobs in the same poloidal plane may also merge with each other [4], and thereby also contribute to anomalous transport in the edge region. In view of their intrinsic unidirectional/monopolar current [5, 7] as well as inherent strong electron and ion temperature gradients [8], ELM blobs have a distinctive dynamics that has not received as much attention as the conventional blobs. In particular, the effect of ion temperature and ion temperature gradient on their evolution, stability, and interaction with the plasma has not been investigated to date. Our present work is devoted to a detailed investigation of such an effect using extensive fluid simulations.

Our model equations are based on the reduced form of the Braginskii equations [9] in a three-dimensional (3D) Cartesian geometry, where the magnetic field is directed along the z-direction, and the x and y axes represent the radial and poloidal directions, respectively. The plasma β is assumed to be sufficiently high so that the inductive component of the electric field cannot be neglected, and electromagnetic effects are retained. To numerically simulate our model equations, we utilize the BOUT++ framework [10], enabling a detailed exploration of ELM blob dynamics in high-β plasmas. The numerical simulation of this model is done using typical edge input parameters [4]: $n_0 \sim 10^{14}\ cm^{-3}$, $T_{e0} = T_{i0} \sim 200\ eV$, $B_0 \sim 5.3 \times 10^4$ G, R $\sim$ 600 cm, $\beta = 2.87 \times 10^{-4}$, and $L_z = 2\pi Rq \sim 10^4$cm. We assume periodic boundary conditions in the y-direction and Neumann boundary conditions in the x and z directions for all evolving variables. The typical grid size used in our simulation is $N = N_x \times N_y \times N_z = 516 \times 512 \times 32$ [4]. The spatial step sizes in x, y and z directions are $dx = dy = 0.5\rho_s$ and $dz = 8012\rho_s$.

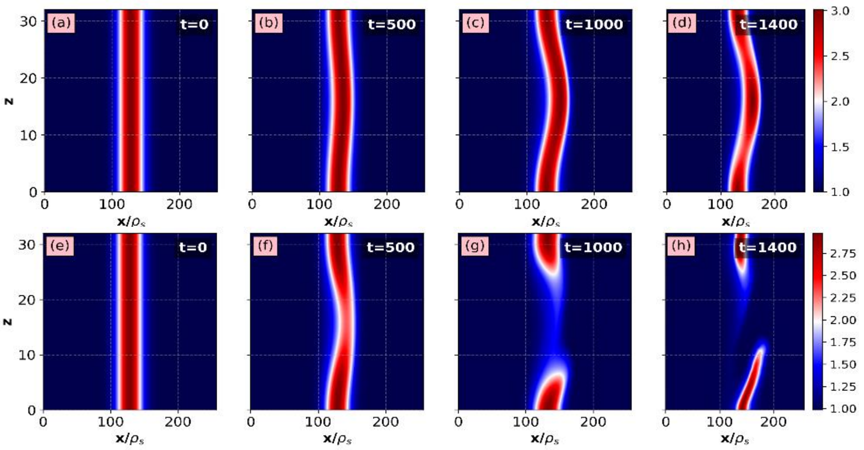
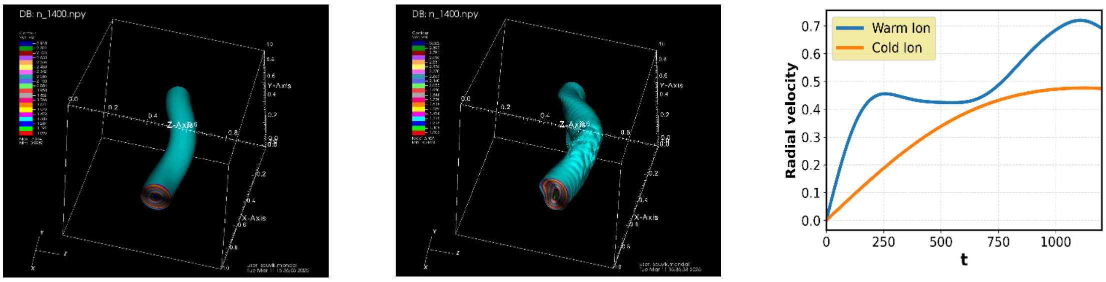


Figure 1: 2D snapshots comparing the time evolution of an ELM blob with cold ions (a-d) with that of an ELM blob with warm ions (e-h). The amplitude of the initial current density $J_0 = 0.5$ with $n_b = 2$ [4].

To show the role of T_i, Fig.1 gives 2D snapshots charting the time evolution of a blob in the x-z plane at $y = L_y/2$, for two scenarios: a cold-ion case (a)-(d) and a warm-ion case (e)-(g). Initially, a Gaussian-shaped density profile is seeded along with a parallel unidirectional current density $J_0 = 0.5$ (~ 0.8 MA/m^2). In both cases, the blob exhibits rotational motion about its axis, while the hot ion blob shows a flow of the plasma density along the parallel direction due to the onset of an instability. The ion temperature gradient instability is responsible for the decrease of plasma density at the outermost midplane, Fig. 1(f)-(g).



(a) Cold ion blob (b) Warm ion blob (c) Radial blob velocity

Figure 2: 3D plots of the filamentary ELM blob for the cold ion (left), the warm ion (middle), and the radial blob velocity (right) over time. The center of mass (COM) of the blob has an initial current density of $J_0 = 0.5$, with $n_b = 2$. The 3D snapshots are taken at t=1400/Ω_s [4].

The plasma blob motion in the radial-poloidal plane is also investigated to identify the role of T_i. The hot ion blob moves considerably in the poloidal direction by $E_x \times B$ flows compared to the cold ion case. Notably, because of the presence of a unidirectional current within the blob (hot or cold ions), it does not develop the characteristic mushroom-like structures observed in dipolar blobs. The 3D plots in Fig.2 (a)-(b) further reinforce these observations, revealing the filament in the warm-ion case. The hot ion blobs' surface is distorted compared to the colder ion blobs. The radial velocity of these two types of blobs, estimated from the center-of-mass (COM) position, reveals (see Fig.2 (c)) that the warm-ion blob moves faster than the cold-ion blob, primarily due to the additional temperature-related term contributing to the effective gravity. However, a decrease in radial velocity between $t = 250$ to $t = 600\ /\Omega_s$ in the warm-ion case suggests the influence of non-linear interactions involving the ion temperature gradient. The rotational speed will be presented using Fourier-Mellin transform based method.

To summarize, our simulations show that ion temperature can significantly influence the dynamics of the ELM blobs such as their radial velocities, internal plasma flows, and rotational motion that can impact their contribution to transport and plasma-wall interactions in high beta machines like ITER and future DEMO devices.

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