Gyrokinetic simulation of GAMs in Textor plasma edge

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Introduction

Recently, the global full f nonlinear gyrokinetic code ELMFIRE [1] has been validated against direct measurements of micro-, meso- and macroscale transport phenomena in the FT-2 tokamak [2]. Now, a similar effort has been started for the middle-sized tokamak TEXTOR. In this paper, the ELMFIRE study of GAMs for L-mode case is continued. The spatial and temporal correlation between GAMs as well as effect of isotope are investigated.

GAMs and their effect on $\omega_{E\times B}$

Elmfire is a full f gyrokinetic guiding-centre orbit following code. Collisions are evaluated using a binary collision model and kinetic electron and ion species are followed. Numerical details are given in [1]. Code has been benchmarked against the Cyclone base case and detailed predictions of neoclassical properties as well as direct measurements of micro-, meso- and macroscale transport phenomena in the FT-2 tokamak [2]. In Ref. [3], ELMFIRE was used for the simulation of TEXTOR tokamak [4]. There, strong GAM oscillation in L-mode simulation was observed while with the H-mode parameters oscillation at the top of pedestal was much weaker. In order to study the GAMs we use similar parameters as in the L-mode case of Ref. [3]. Here, $a = 0.46$ m, $R = 1.75$ m, $B_T = 1.3$ T and $I = 235$ kA where a is the plasma minor radius, R the major radius, B_T the toroidal magnetic field, and I the plasma current. For temperature and density, hyperbolic profiles $T = T_0 \times [1+0.95\tanh(r_{mid}-r)/(0.95L_T)]$ and $n = n_0 \times [1+0.95\tanh(r_{mid}-r)/(0.95L_n)]$ are used as a starting point of our simulations. Here, $r_{mid} = 0.375$ m, $n_0 = 0.7\times10^{19}$ m^{-3}, $T_0 = 150$ eV, $L_n = 3$ cm and $L_T = 6$ cm Pure deuterium plasma is simulated in a 15 cm wide regime ($r = 0.3-0.45$ m) and 940 million electrons (11200/cell) and ions are followed in a $N_r = 100$, $N_\chi = 210$ and $N_\phi = 4$ grid. For thermal $T = 200$ eV particle, Larmor radius is $\rho_L = 2.22$ mm and radial and poloidal resolutions normalized to this are $\Delta r \approx 0.6\rho_L$ and $r\Delta\chi \approx (5-6)\rho_L$. Time step is $\Delta t = 0.1\mu$s and 7000 timesteps are simulated which is $t = 0.7$ms ($\approx 15-20$ bounce times for $T = 200$ eV ion). Simulation required 334000 CPU hours on Intel Xeon Sandy Bridge-EP processors.

In Fig. 1a, a clear GAM oscillation is seen. From the figure, phase shift of λ over 2 cm can be estimated which is in rough agreement the analytic theory [5] for which the radial mode is Airy

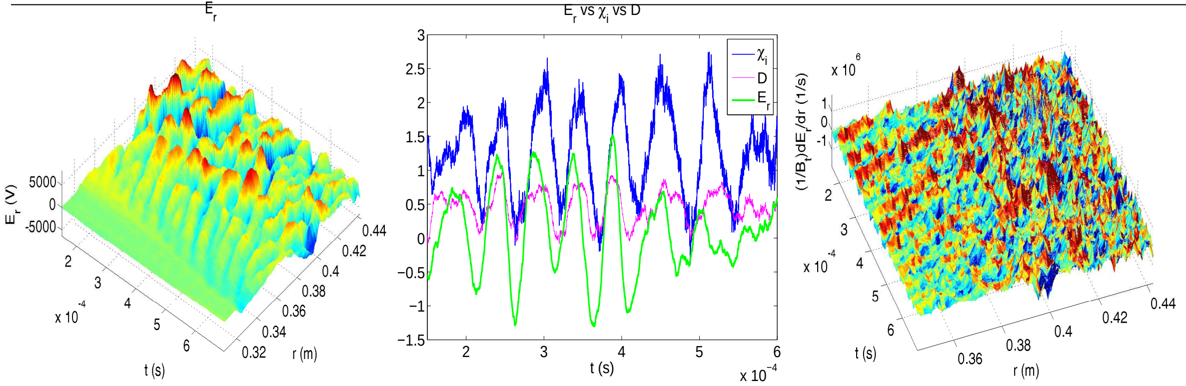

Figure 1: *a)* $E_r(r,t)$*, b)* $E_r(t)$ *vs* D *and* χ_i*, and c)* $\omega_{E\times B}$

function with characteristic scale of $\lambda = 0.9$ cm (the wave length is few times λ). In Fig. 1b, a clear correlation between oscillation of $E_r(t)$ and transport coefficients is observed at $r = r_{mid}$.

As clear GAM oscillations are seen using L-mode parameters and also in some AUG experiments before L-H transition it is of interest to look at the $E \times B$ shear values due to radial eigenmode of the oscillation. In Fig. 1c, $\omega_{E\times B}$ values estimated from the data of Fig. 1a, are shown to achieve values even up to 10^6 s^{-1}. This can be compared to the BDT (Biglari-Diamond-Terry) criterion for the strong suppression of turbulence which is $|\nabla E/B| > \Delta\omega_t/k_\theta\Delta r_t$ [6]. Here, $\Delta\omega_t$ is the turbulent decorrelation frequency, Δr_t is the radial correlation length, and k_θ is the mean poloidal wave number of the turbulence. Typical values observed at DIII-D are $\Delta\omega_t = 2.5\times10^5$ s^{-1}, $\Delta r_t = 0.7$ cm^{-1} and $k_\theta = 1$ cm^{-1} [7] which gives criterium $\nabla E/B > 3.6\times10^5$ s^{-1}. Thus, values shown already exceeds the BDT-criterion locally over range of Δr_t and temporally for time of $1/\omega_t$ and we may speculate can this shear have a role in triggering of L-H transition. The critical shear as a function of A, B_t and I has been studied experimentally [8] in TEXTOR-94 and the dependence $\nabla E_{crit} \approx 61\times B_t^{1.4}A^{-1.2}I^{-1.66}$ (in kV m^{-2}, T, amu, MA) was found which for present case gives $\nabla E_{crit}/B_t = 3.2\times10^5$ s^{-1}.

Isotope scan

The simulation of the deuterium case shown in previous section is here repeated changing the isotope while keeping all the other parameters fixed. Here, hydrogen ($A = 1$, $Z = 1$), tritium ($A = 3$, $Z = 1$) and helium ($A = 4$, $Z = 2$) are considered. In Fig. 2, radial electric field as a function of time and radius is shown for all four cases. GAM oscillation can be seen in all cases and in all cases also the maximum of GAMs (seen in red) moves radially outwards as a function of time. The speed of this radial propagation, $v_{r,GAM}$, estimated from the figures is shown in Fig. 3a and roughly scales as $v_{r,GAM} \propto 1/\sqrt{A}$. Also, the distance between the GAMs

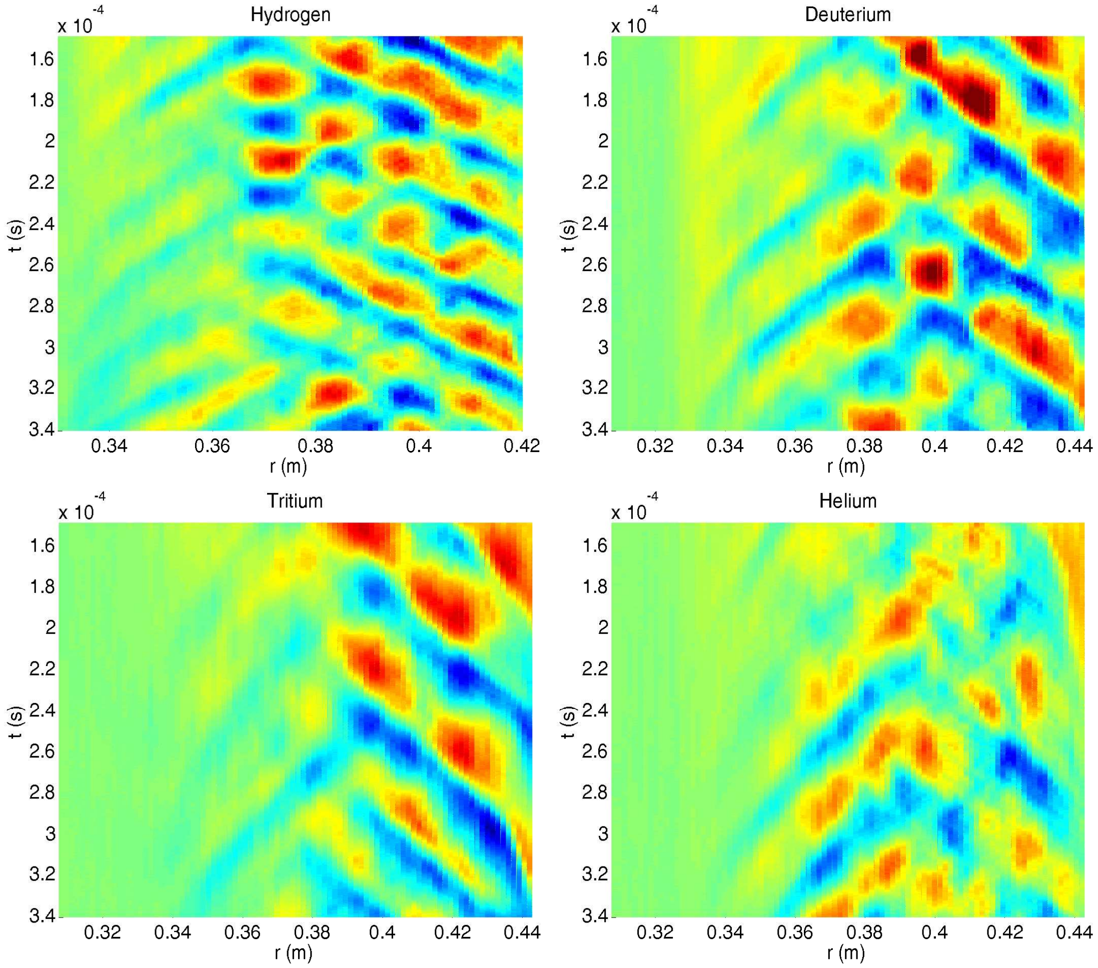

Figure 2: $E_r(r,t)$ *for a) hydrogen, b) deuterium c) tritium and d) helium case*

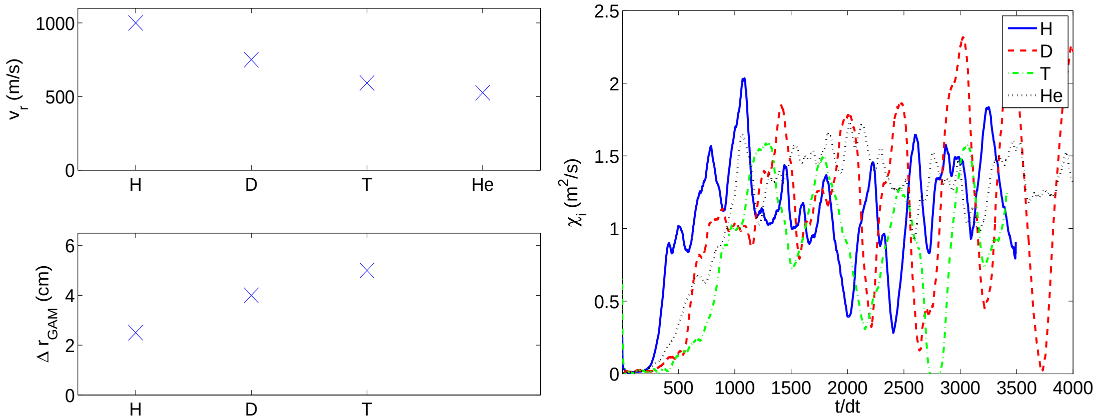

Figure 3: *a) The radial propagation of GAMs (upper figure), distance between the GAMs (lower figure) and b) heat diffusivity* $\chi_i(t)$ *for all for isotopes*

is shown in Fig. 3a and scales roughly $\propto A^{0.6\pm0.2}$. In Fig. 3b, heat diffusivity values at $r = r_{mid}$ are shown for all four cases. In Ref. [9] favourable mass scaling for χ_i was observed where ITG-turbulence was investigated. Here, however, any clear scaling is not observed. One should note, however, that in present simulation also kinetic electrons and neoclassical transport are included and parameters are different.

Conclusions

In this paper, a clear correlation between E_r and transport coefficients was found and ω_{ExB} due to phase shift of GAMs were found to reach values which may affect the transport levels. However, no clear correlation between $E \times B$ shear and χ_i is observed in the simulations. Clear isotope dependence in phase shift and radial propagation velocity of GAMs was observed. Similar values for the level of radial probagation velocity have been measured for Textor in Ref. [10] but since the parameters are not exactly the same, exact comparison to experiments is left for future work.

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