

Gyrokinetic simulation of interplay between GAM and transport in TUMAN-3M tokamak

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Geodesic acoustic mode (GAM) is a type of radial electric field (E_r) oscillation which has been proposed to regulate turbulence level. It adds a time varying component to the E_r shear in addition to shear in time-averaged E_r . Recently, the full f gyrokinetic code ELMFIRE [1] has been used for simulating the isotope effect in turbulent transport control by GAM in FT-2 tokamak [2]. Also, in Ref. [3], the code was used to investigate the parametric dependence of transport properties. At the same time, a model based on 1D density evolution depending on E_r shear has been developed [4]. In the model, the L-H transition in TUMAN-3M is proposed to be triggered by a burst of GAM oscillations. In the present paper, the ELMFIRE code is used to study the interaction of GAM and the transport coefficients using TUMAN-3M parameters.

Simulation parameters

Elmfire is a full f gyrokinetic particle-in-cell code. Collisions are evaluated using a binary collision model and kinetic electron and ion species are followed. Numerical details are given in [1, 5]. In order to study the GAMs we use the parameters of L-mode, early H-mode (1.5 ms after transition) and late H-mode (12.5 ms after transition) plasmas in TUMAN-3M [4]. Here, $a = 0.22$ m, $R = 0.53$ m, $B_t = 0.7$ T and $I = 128$ kA where a is the plasma minor radius, R the major radius, B_t the toroidal magnetic field, and I the plasma current. For electron temperature, $T_e(r)$, experimental profile from Thomson scattering is used. The density profile, $n_e(r)$, is measured with 10 channel microwave interferometer. For ion temperature only central temperature measured with NPA is available and the shape of the profile in L-mode is assumed to be same as for electron temperature, i.e. $T_i(r) \propto T_e(r)$. For the H-mode cases we use the shape of the L-mode $T_i(r)$ scaling it up by factors 1.1 (early H-mode) and 1.5 (late H-mode). The initial profiles used in the simulations for the three cases are shown in Fig. 1. The deuterium plasma with Carbon C^{6+} impurities ($Z_{eff} = 1.2$) is simulated over the whole cross-section [5] starting from axis. 930 million electrons (average of 1800/cell) and 843 million ions (1600/cell) and 14 million impurities (27/cell) are followed in a $N_r \approx 100$, $N_{\chi,max} = 1200$ and $N_\phi = 8$ grid totalling to 523000 grid points in L-mode case. Loop voltage is $U_{loop} = 1.5$ V, 1.33 V and 1.762 V, in

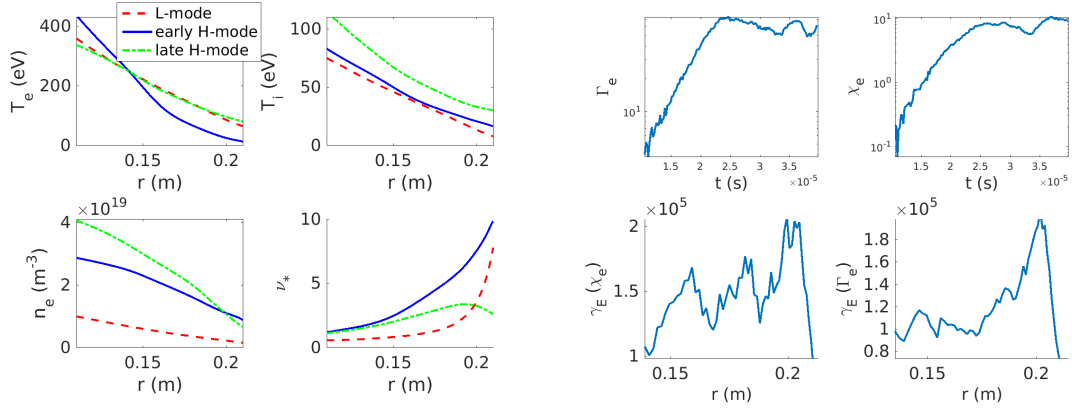


Figure 1: Left: Initial temperature and density profiles in the simulations. Right: $\Gamma_e(t)$ and $\chi_e(t)$ at $r = 17.3$ cm (top) and growth rate of these quantities.

L-mode and early/late H-mode, respectively. Here, both grid cell size in radial direction (determining N_r) and number of grid points in poloidal direction $N_\chi(r)$ depend on local value of Larmor radius which varies as a function of radius. The safety factor is $q < 1$ up to $r = 12$ cm. Since sawtoothing, which is not included in Elmfire, is expected to dominate transport in this region, only results for $r > 12$ cm are shown. The relatively small B_t makes the CPU time usage of the simulation modest since for deuterium particle and $T_e = 100$ eV one gets $\rho_s = c_s/\Omega_i = 2.0$ mm and thus $\rho_* = \rho_s/a = 0.009$ which also indicates that global simulation is necessary for reliable results [6]. Here, $c_s = \sqrt{T_e/m_i}$ is the sound speed. Time step in the simulation is $\Delta t = 20$ ns and 8000 time steps are simulated which is $t = 160\mu s$.

Results

In Fig. 2a the radial electric field E_r is shown in radius and time showing strong GAM oscillations. In Fig. 2b the frequency of this oscillations is Fourier analysed showing the main frequency of $f_{GAM} \approx 40 - 50$ kHz which is some 50 % more than in experiments referring to that the choice of $T_i(r)$ profile may not be correct. Also, in experiments GAMs are only observed at very edge while in simulations there are strong oscillations over a wide range ($r = 13 - 20$ cm). Magnitude of GAMs $\delta E_r = \pm 2.5$ kV/m is also less than in experiments ($\pm 4.5 - 5$ kV/m).

In Fig. 1 (top right) typical time behaviour of electron particle flux Γ_e and heat conductivity χ_e in L-mode case are shown for one representative radial position ($r = 17.3$ cm). In the bottom figures a rough estimate for growth rates of these two quantities in the beginning of the simulation (between $t = 15 - 30\mu s$) is estimated from $\chi_e(t) = \chi_e(t_0) \exp(\gamma_E t)$ for several different radial positions. One should note that since $\Gamma_e \propto \langle \delta n \delta \phi \rangle$ and $\chi_e \propto \langle \delta T \delta \phi \rangle$ the linear growth rate of \tilde{n} , \tilde{T} and $\tilde{\phi}$ is expected to be factor 2 smaller than that of Γ_e and χ_e i.e. $\gamma = \gamma_E/2$. Average

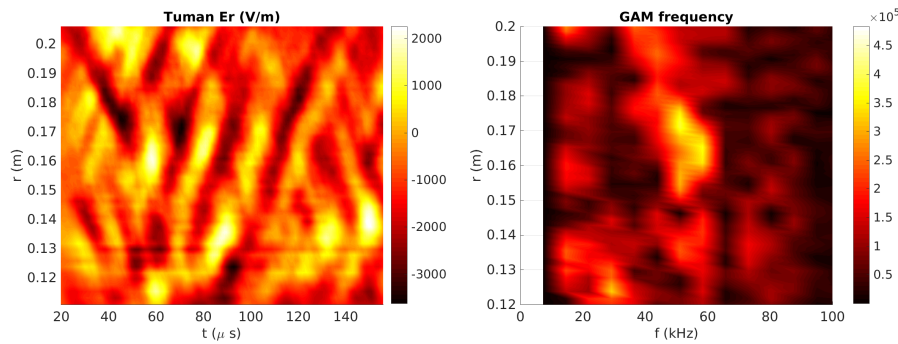
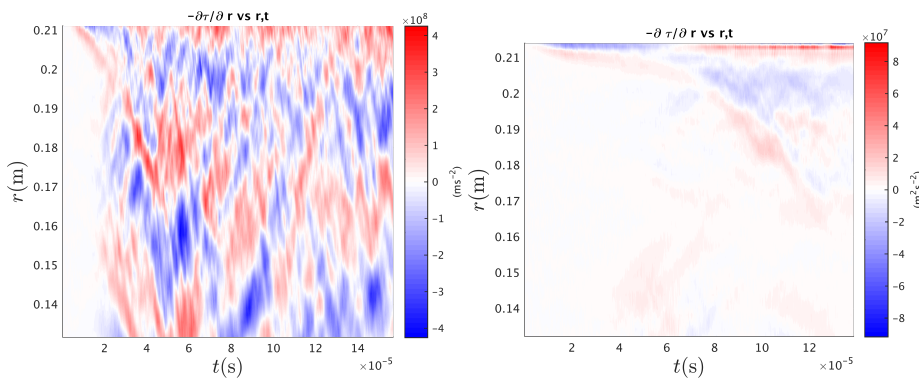
Figure 2: a) Fluctuations in E_r and b) GAM frequency

Figure 3: Reynolds stress drive in L-mode (top) and early H-mode (bottom)

over 15-20 cm gives $\gamma = 0.75 \times 10^5 \text{ s}^{-1}$. Flux surface and time averaged values for Γ_e , E_r , $\chi_{e,i}$ and $D_{e,i}$ for all three cases are shown in Fig. 4. A drastic drop in transport coefficients is seen when going from L-mode to early H-mode case. Late H-mode case is between these two cases showing increased transport compared to early H-mode but still much below the L-mode case. Flux surface averaged E_r remains relatively small. Maximum of $E \times B$ shear ($r = 15 - 17$ cm in the figure) just after the transition is about $\omega_{E \times B} = 3 \times 10^4 \text{ s}^{-1}$. Same analysis as in Fig. 1 gives $\gamma \approx 4 \times 10^4 \text{ s}^{-1}$ for the turbulence growth rate at the position of strongest $\omega_{E \times B}$ in early H-mode indicating that shear is close to the turbulence suppression criterium $\omega_{E \times B} > \gamma$. A drastic drop in Reynolds stress drive is also seen from L-mode to early H-mode, see Fig.3.

Conclusions and discussion

Tentative simulations for three TUMAN-3M cases were shown. Clear drop in transport coefficients was seen when going from L- to H-mode. Strong correlation between time behaviour of GAMs and particle diffusion was seen in L-mode. Amplitude of GAMs is smaller, frequency is higher and GAM region extends much deeper in the Elmfire simulations compared to experiments. Explanation for disagreement is probably that accurate ion temperature data was

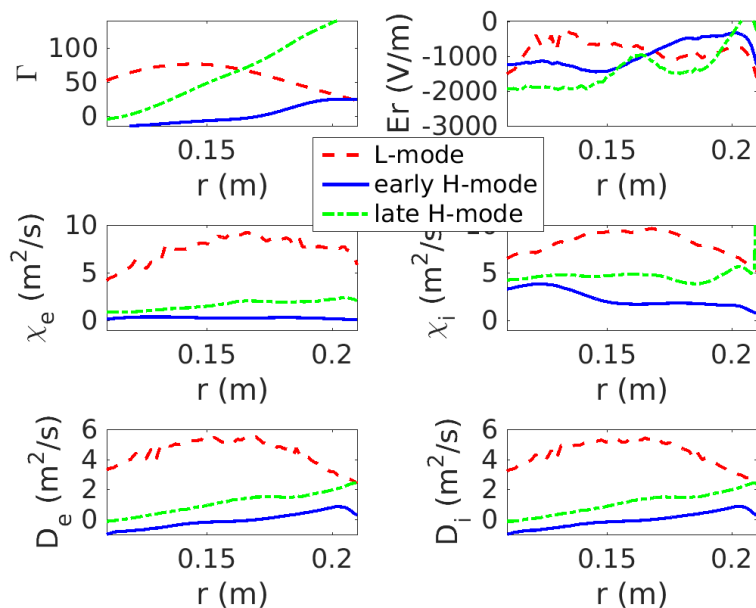


Figure 4: Flux-surface- and time-averaged particle flux, $E_r(r)$ and transport coefficients.

not available. Also, the fact that GAMs are not observed further in may be just a limitation in experimental diagnostics.

Acknowledgements: This work is supported by grant 278487 of the Academy of Finland and has received funding from Tekes – the Finnish Funding Agency for Innovation under the Finn-Fusion Consortium. CSC – IT Center for Science Ltd. and Helios at IFERC-CSC are acknowledged for allocation of computational resources for this work. Co-authors of the paper would like to acknowledge partial financial supports of RFBR grants 16-02-00580 (A. Gurchenko) and 15-02-03766 (E. Gusakov).

References

- [1] J.A. Heikkinen, S.J. Janhunen, T.P. Kiviniemi and F. Ogando, *J. Comp. Phys.* **227**, 5582 (2008).
- [2] A. D. Gurchenko et al, *Plasma Phys. Control. Fusion* **58**, 044002 (2016).
- [3] P. Niskala, T.P. Kiviniemi, S. Leerink, T. Korpilo, *Nucl. Fusion* **55**, 073012 (2015).
- [4] L.G. Askinazi, V.I. Afanasyev, A.B. Altukhov et al, *Nuclear Fusion* **55**, 104013 (2015).
- [5] T. Korpilo, A.D. Gurchenko, E.Z. Gusakov, J.A. Heikkinen, S.J. Janhunen, T.P. Kiviniemi, S. Leerink, P. Niskala, *Computer Physics Communications*. **203**, 128 (2016).
- [6] B. F. McMillan, X. Lapillonne, S. Brunner, L. Villard, S. Jolliet, A. Bottino, T. Görler, and F. Jenko *Phys. Rev. Lett.* **105**, 155001 (2010)