Studying effect of plasma parameters on geodesic acoustic modes via gyrokinetic simulations

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Plasma confinement is a key aspect for efficient fusion reactors. Transport of particles and energy out of the plasma and towards the walls of the tokamak reduces confinement. Turbulence plays a key role in increasing these losses, and thus learning to understand and ultimately control turbulence is a crucial goal for fusion research.

Zonal flows present a possible mechanism for controlling turbulence. These flow oscillations are seen in a tokamak due to the toroidal magnetic geometry of the device. Turbulence drives a potential oscillation component that is constant on a magnetic surface, and this creates an oscillation in the electric field and in turn oscillation in the $\mathbf{E}\times\mathbf{B}$ drift flow. A density accumulation occurs, since the strength of the magnetic field increases when moving towards the inner side of the torus and thus the flow velocity is not constant on the magnetic surface [1].

While the zonal flows can be practically stationary in time and only vary in space, the geodesic acoustic mode branch of zonal flows has a finite temporal frequency. These oscillations have been connected to enhanced confinement due to shearing of turbulent structures caused by fluctuations in the $\mathbf{E}\times\mathbf{B}$ velocity.

Here we have investigated the effect of various plasma properties on the features of geodesic acoustic modes using parameters of the TEXTOR tokamak. The flow oscillations were studied using ELMFIRE, a full-f code capable of simulating both neoclassical and turbulent plasma physics in a circularly symmetric geometry [2]. The gyrokinetic and electrostatic code includes a binary collision model, while both ions and electrons are treated kinetically. Previously, comprehensive analysis has been done on FT-2 tokamak plasmas [3].

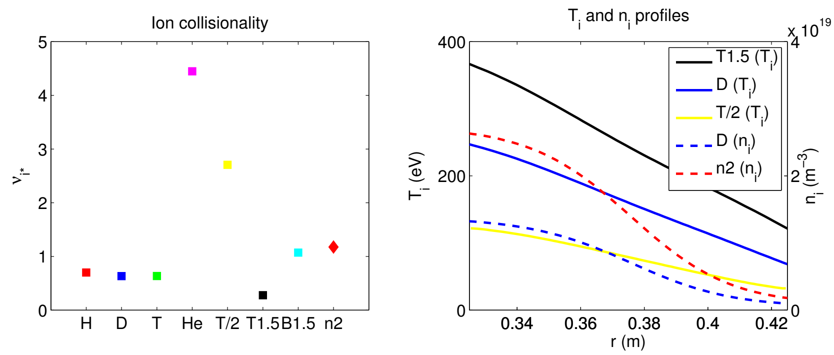

Figure 1: *The mean collisionality of the simulations varied from banana to banana-plateau regime.*

Plasma parameters were chosen roughly based on a TEXTOR L-mode discharge. The temperature profiles (shown in figure 1) were hyperbolic with $L_T = 6$ cm and $L_n = 3$ cm at the middle radius. Toroidal magnetic field was set to 1.3 T and plasma current to 235 kA. The simulation region was limited radially to $\rho = 0.64 - 0.98$. The simulation grid had 210 poloidal, 100 radial and 4 toroidal grid points. Typically simulations lasted 600 μs with a timestep of 0.1 μs. No impurities were included in the simulations.

Simulations were run with varying temperatures, densities, magnetic field strengths and ion species. The collisionality of these cases varied from the banana regime to banana-plateau regime, as seen in figure 1. It was calculated as $\nu_{i*} = \varepsilon^{-3/2}\frac{q_s R_0}{\tau_{ii} v_t}$ using the safety factor q_s, inverse aspect ratio ε, major radius R_0, thermal velocity $v_t = \sqrt{2T/m}$, and collision time τ_{ii}. The collisionality was the main difference compared to the previous work on the smaller FT-2 tokamak.

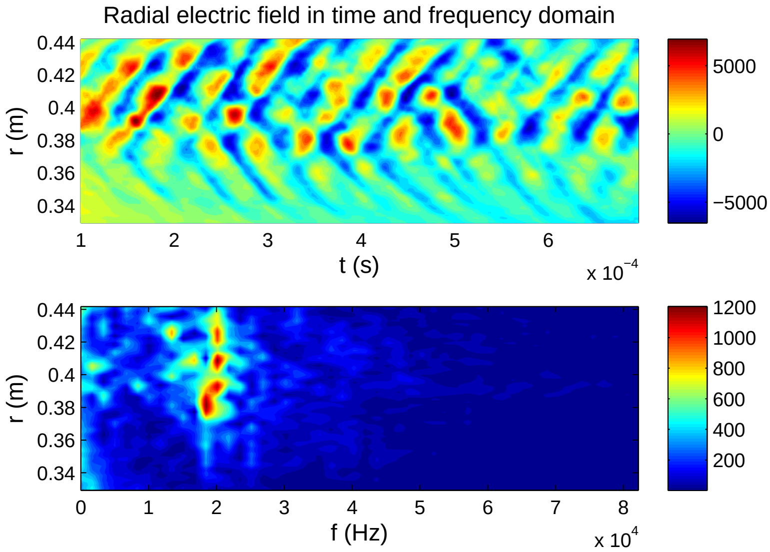

Figure 2: *The radial electric field shows clear fluctuations for the deuterium case. The spectrum has clear peaks at expected GAM frequencies.*

The frequency spectrum of figure 2 shows clear peaks at appropriate GAM frequencies in the kilohertz range. The results were qualitatively similar across the simulation series. For the GAM frequency, there is the analytic estimate

$$f_{\mathrm{GAM}} = \frac{1}{\sqrt{2}\pi R_0}\sqrt{(T_i + \frac{7}{4}T_e)/m_i}, \tag{1}$$

while Itoh et al. presented that wavelength of the oscillations would scale as a function of temperature gradient scale length L_T and ion gyroradius ρ_i [4]:

$$\lambda_{\mathrm{GAM}} \sim \rho_i^{2/3} L_T^{1/3}. \tag{2}$$

The simulation results do not show the radial dependency of the analytic frequency estimate, most likely due to limited frequency resolution, but otherwise the agreement is good, as shown in figure 3. The estimated wavelengths were also found to scale as expected based on the theory, even though this was not the case for FT-2 experiments and simulations [7]. This might be due to distinct differences in collisionality.

Figure 2 also shows the clear oscillations of radial electric field. They propagate radially inwards and outwards in the simulation region. This is consistent with observations from experiments [5] and simulations [6]. The inward propagation was located roughly in the inner half of the simulation region, while the outward propagation existed in the outer half. Figure 4 shows how the time lag of the peak for the cross-correlation coefficient increases linearly as radial separation is increased, providing us with the radial propagation speed v_r, which decreases as function of mass for both directions.

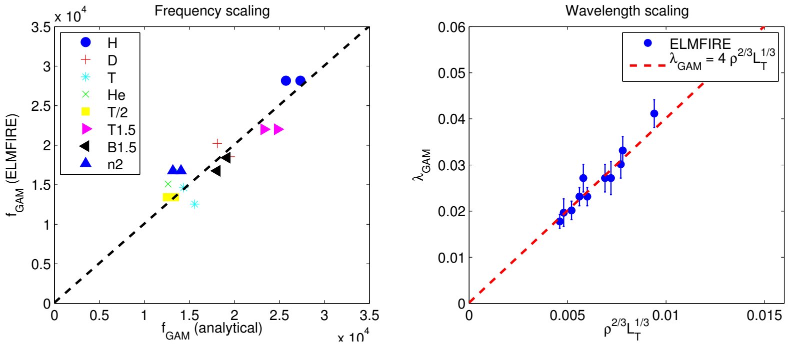

Figure 3: *The frequency and wavelength of E_r oscillations scales as expected based on theory and analytical expressions.*

Cross-correlation analysis also shows a clear correlation between the radial electric field and transport fluxes as seen in figure 4. This is consistent with the theory of geodesic acoustic modes. The behaviour was observed for all of the simulation cases, but the extent of the correlated radial region varied. The phase difference for e.g. E_r and Γ was generally between 130 and 160 degrees, while for heat fluxes q_e and q_i the phase differences were roughly half of that. Interestingly the phase differences between E_r and q_e were of different sign compared to E_r and q_i.

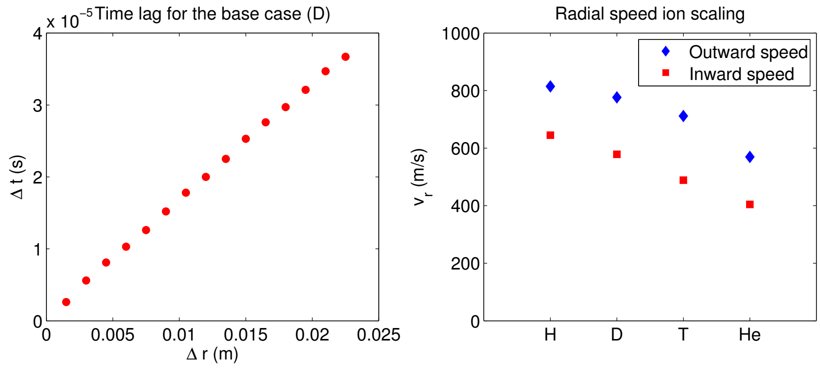

Figure 4: *The time lag increases linearly as radial separation between signals is increased. Both the inwards and outwards propagation speed of the radial electric field fluctuations scales as a function of ion mass.*

Same kind of consistent correlation was not observed for the shear of the radial electric field, $\frac{\partial E_r}{\partial r}$, although oscillations were also present in the shear. In the predator-prey models, the shear often takes the role of the predator instead of E_r. The direction of the phase shift between e.g. E_r shear and Γ was dependent on the direction of the radial propagation.

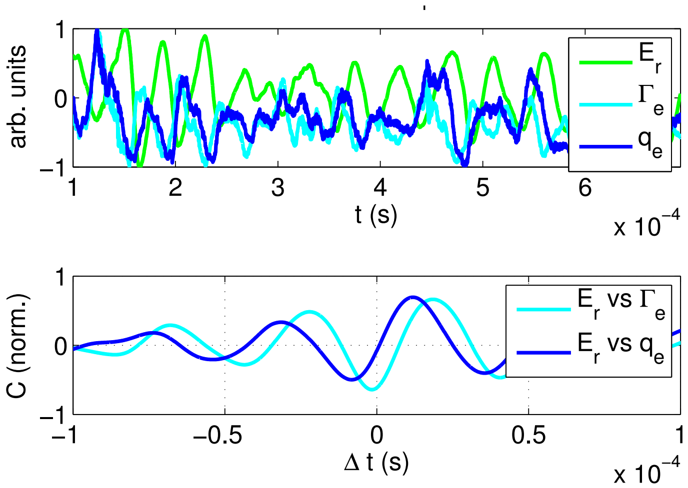

Figure 5: *The time traces for E_r, D and χ_e show clear correlation on the same radial point. This is verified by the correlation coefficient.*

Future research should include direct comparisons with experiments and systematic scans for machine independent parameters such as collisionality and amount of impurities, although experimental comparisons are made more difficult by computational requirements. Here we concentrated only on the radial electric field E_r calculated based on the the flux surface averaged potential, even though the theory of geodesic acoustic modes couples the potential fluctuation to a density fluctuation. The comparisons would require development of synthetic diagnostic methods and analysing density fluctuations besides the electric potential.

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References

[1] N. Winsor, J.L. Johnson, and J.M. Dawson, Physics of Fluids **11**, 2448 (1968)

[2] J.A. Heikkinen, S.J. Janhunen, T.P. Kiviniemi and F. Ogando, J. Comp. Phys. **227**, 5582 (2008).

[3] S. Leerink *et al.*, Phys. Rev. Lett. **109**, 165001 (2012)

[4] S.-I. Itoh *et al.*, Plasma Physics and Controlled Fusion **49**, L7 (2006)

[5] T. Ido *et al.*, Plasma Physics and Controlled Fusion **48**, S41 (2006)

[6] F. Liu *et al.*, Physics of Plasmas **17**, 112318 (2010)

[7] A.D. Gurchenko *et al.*, 2013 Espoo Proc. of 40th EPS Conf. on Plasma Physics **37D** P2.181 (2013)