Study of GAM-Turbulence interplay in the FT-2 tokama using GENE

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Introduction The interaction between micro-scale turbulence and meso-scale plasma flows play an important role in the current understanding of improved confinement regimes. Plasma flows are generated by turbulence and often act to suppress the turbulence, creating a self-organizing system. To study the energy transfer between turbulent fluctuations and plasma flows, the zero toroidal and poloidal mode numbers are categorized as zonal flows (ZF) while waves having higher poloidal mode numbers are categorized as turbulent fluctuations. The zero frequency part of the radial electric field is called Zonal flows while the finite frequency oscillations in the radial electric field are called GAMs[1]. GAMs transfer energy from zonal flows to turbulence modes via three-wave coupling[2]. Similarly, there is an energy transfer from turbulence modes to GAMs and ZF due to Reynold's stress. During a L-H transition, transfer of energy from ZF to turbulence is inhibited due to the damping of GAMs, thus ZF continues to shear away turbulent eddies leading to better confinement[3]. GAMs are damped by phase mixing and Landau damping mechanisms during a L-H or L-I transition[4]. Co-existence of these mechanisms potentially leads to intermittency in GAMs and turbulence amplitudes[5].

Recent experimental results in the FT-2 tokamak observed intermittencies in GAM and turbulence amplitudes over a period of 13 ms while the changes in the density and temperature profiles are insignificant [1]. The amplitude of turbulence fluctuations measured by two reflectometers recorded a 21% suppression during the GAM period in the radial region $r/a = 0.4 - 0.8$. To study this interplay between GAMs and turbulence, Reynold's stress needs to be calculated which is an ambitious task in experiments. Gyrokinetic simulations are used to study the interplay between GAM and turbulence by developing synthetic diagnostics that can quantify the non-linear energy transfer between GAMs and turbulence.

Simulation setup A global, non-linear, electromagnetic simulation covering the radial domain tor = 0.475 0.725 of the FT-2 tokamak is performed with the GENE code [6]. The reference discharge for this simulation is the Wagner case [1]. The simulation lasted 7.47 ms, sufficient to observe several GAM intermittency period. The main ion species is D+, and the main impurity species is O7+. All plasma species including the electrons are treated as kinetically. Collisions are modeled using the Landau collision operator. The required magnetic equilibrium is obtained by approximating FT-2 tokamak magnetic equilibrium as a circular

[1]There is also a low frequency ($\approx$ 2 kHz) part of the radial electric field called as Zonal flow oscillations (ZFO).

one. The temperature of ion and impurity species are equal in the radial direction (Fig. 1). The grid resolution is $n_x n_y n_z n_{v0} n_{w0} = 128 \times 32 \times 24 \times 48 \times 16$. The buffer zones in the simulation are set to 7% on both sides of the radial domain. The Dirichlet boundary condition is used in the radial direction for all fluctuating quantities such that their gradients go to zero at the boundaries. The value of Krook-type heat and particle source is set to 0.005. The minimum value of the poloidal wave vector in the y-direction is 0.005 (in the unit of inverse gyro-radii). The reference radial position is tor = 0.60 and all plasma parameters of D+ ion at this radius are taken as reference values for the purpose of normalization. Important values at the reference location is given in table 1.

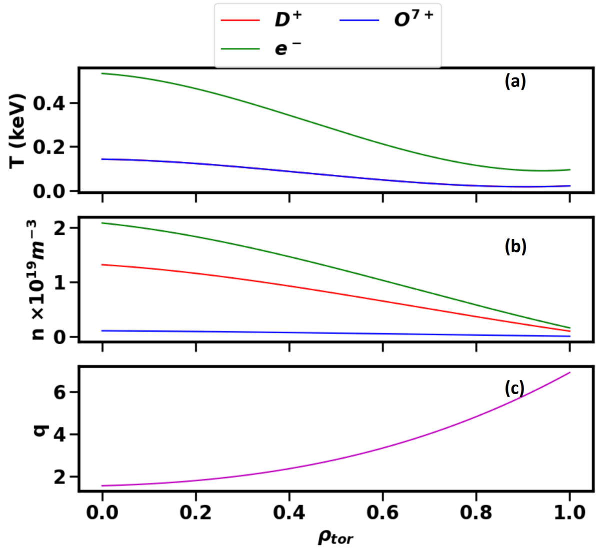

Figure 1: Radial profiles of temperature (a), density (b) and safety factor (c) for the deuterons, electrons and partially ionized oxygen ions O^{7+}.

Reference values					
Density n_0 $(10^{19} m^{-3})$	Temperature T_0 (eV)	Magnetic field B_0 (T)	Larmor radius ρ_{ref} (m)	Velocity $c_{ref}(km/s)$	Length $L_{ref}(m)$
1.028	211.100	2.075	0.0010	10.02	0.55

Table 1: Important reference values used in the GENE simulation.

Modulation of the GAM amplitude GAMs are oscillations in radial electric field and thus taking Fast Fourier Transform (FFT) of the flux surface averaged radial electric field gives the GAM frequency. Welch's algorithm[7] is used for computing the power spectrum of the radial electric field at each radial location as it removes high-frequency components during non-stationary states. This calculation is done in the saturated phase which starts around 1.66 ms. The total time period used for calculation is 0.388 ms which is sufficient for resolving the GAM frequency and this time interval is divided into overlapping time intervals of length 0.0887 ms. The presence of impurities decreases the frequency of GAMs due to collisional damping and the analytical expression for GAM frequency in the presence of impurities is given by Guo et al[?]is

$$f_{GAM} \approx 2\pi \left[\frac{2T_i}{R^2} \left(\frac{7/4(n_i + n_z) + A}{n_i m_i + n_z m_z} \right) \right]^{\frac{1}{2}} \quad (1)$$

where the term $A = n_i \tau_i \frac{n_i q_i}{q_e n_e} + n_z \tau_z \frac{n_z q_z}{q_e n_e} + n_i \frac{q_i}{q_z} \tau_z \frac{n_z q_z}{q_e n_e} + n_z \frac{q_z}{q_i} \tau_i \frac{n_i q_i}{q_e n_e}$, $\tau_{i/z} = q_{i/z} T_e / (q_e T_{i/z})$, $q_{i/e/z}, n_{i/e/z}, T_{i/e/z}$ and $m_{i/z}$ is the charge, density, temperature and mass of ions, electrons and impurities.

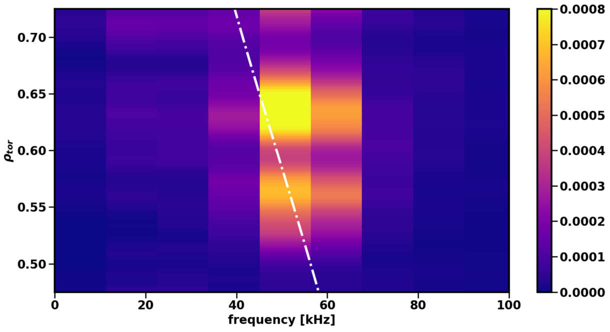

Figure 2: Power spectra of the radial electric field computed using Welch's algorithm. The white dash-dotted line is the GAM frequency given by the analytical expression at different radial locations.

Power spectra of the radial electric field indicate that the GAMs dominate around radial locations ρ_{tor}=0.63 and 0.55. Fig. 2 shows that frequencies of GAMs at these radial locations are around 48 kHz which is very close to the analytical prediction as given by Eq.1 .

Intermittencies in the GAM activity are seen by integrating the power spectra between radial positions $\rho_{tor} = 0.59 - 0.652$ and selecting frequencies between 42 kHz and 56 kHz. Fig. 3 shows that there is a drop in the GAM activity around 3 ms, 4.5 ms, 5.5 ms, 6.4 ms and 7.1 ms. This intermittency in the power spectra indicates there is a transfer of energy from turbulence to GAMs and vice versa.

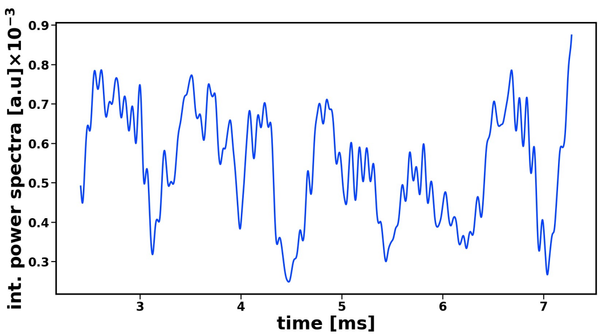

Figure 3: The integrated power spectra of the radial electric field computed using Welch's algorithm.

Nonlinear couling between GAMs and Turbulence Using the bicoherence technique, non-linear coupling between turbulence fluctuations and GAMs at different time intervals and at different poloidal angles is calculated. The bicoherence between density fluctuations and radial electric field at $\rho_{tor} = 0.63$ at the High field side (HFS) from t=1.66 ms to 2.05 ms and 2.05 ms to 2.4 ms. The coupling between GAMs and turbulence is strong during the time period between t=1.6 ms to 2.05 ms, indicating a transfer of energy from turbulence to GAMs, causing the rise in GAM amplitude and the inverse is observed during the time period 2.05 ms to 2.4 ms (Fig. 4).

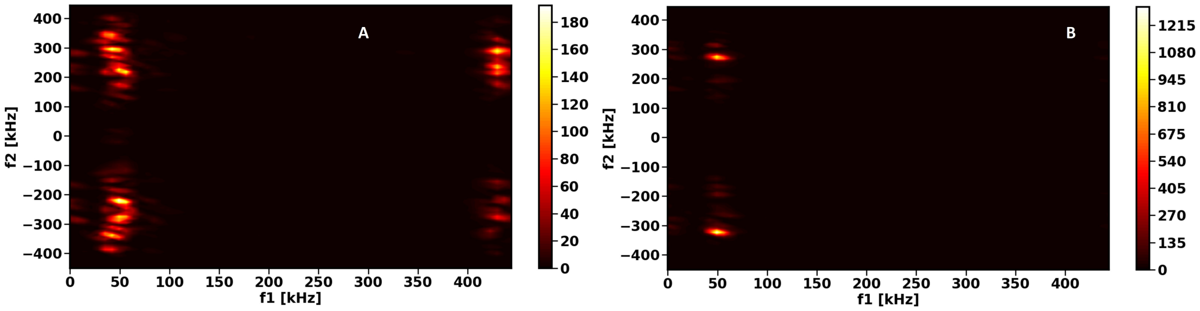

Figure 4: Non-linear coupling between turbulence fluctuations and GAMs from t=1.66 ms and 2.05 ms at the HFS is calculated.

Conclusion and Outlook A global simulation of the FT-2 tokamak using the gyrokinetic code GENE was performed to study the interplay between GAM and turbulence in the FT-2 tokamak. Initial analysis showed frequencies of GAMs match well with the analytical estimate. Radial locations of GAMs are around ρ_{tor}=0.63 and 0.55. The integrated power spectra showed intermittencies in the GAM activity confirming the ubiquitous phenomenon of interplay between flows and turbulence in magnetised plasmas and this is confirmed the bicoherence analysis which showed a strong coupling between GAM and turbulence correlating with the rise in the amplitude of the GAM. The GAM-turbulence interplay is a non-linear phenomenon involving many different damping and driving mechanisms, thus a complete picture requires the understanding of all these mechanisms and identifying the role of dominant mechanisms.

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