MHD-DRIVEN GLOBAL GAM IN ADITYA-U TOKAMAK

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High MHD activity ($|\tilde{B}_\theta|/B_\theta \geq 0.3$ %) with m/n=2/1 is observed to modulate edge plasma potential and density in the ADITYA-U tokamak, leading to the excitation of a coherent mode characterized by m/n=2/1 in $\tilde{V}_p$ and 1/1 in $\tilde{n}_e$ [1]. Upon further exploration of the threshold, it has been found that a critical ratio of the total power spectral density (PSD total) of $\tilde{V}_p$ and $\tilde{B}_\theta$ [1]exists for the excitation of coherent mode in the edge plasma (as shown in Figure 1a). This indicates synchronization (or frequency entrainment) between the driver (MHD mode) and a particular mode in the broadband spectrum of background turbulence at the driver's frequency [1].

To identify the nature of the MHD-induced coherent mode, a detailed investigation has been carried out to understand its excitation mechanism, its effect on background turbulence, and the associated transport. The study reveals that the excitation of the MHD-induced coherent mode increases turbulence decorrelation time, indicating the suppression of high frequency turbulence [2], concomitantly reducing the associated cross field transport ($\Gamma_{\mathrm{turb}} = \ <\delta\tilde{n}_e\delta\tilde{E}_\theta>$), as demonstrated in figure 1b and 1c. In this case, high MHD activity leads to a reduction in turbulence and associated transport by modulating the edge plasma dynamics, contrary to the common understanding of the detrimental effects of MHD activity.

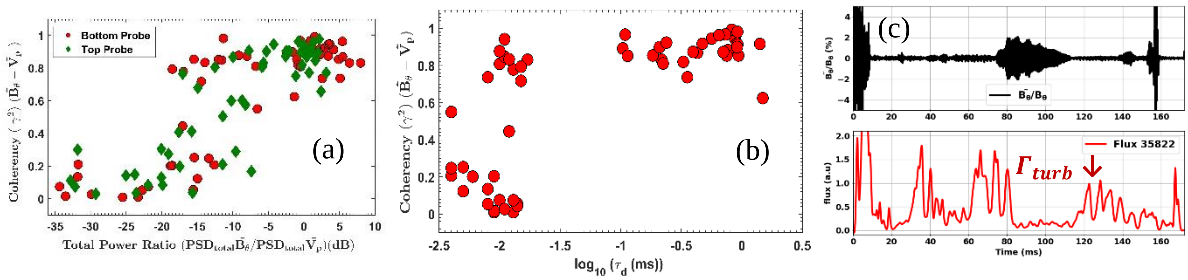


Figure 1: (a) Coherency γ^2 ($\tilde{B}_\theta - \tilde{V}_p$) vs total power ratio of magnetic and potential fluctuations; (b) turbulence decorrelation time with Coherency γ^2 ($\tilde{B}_\theta - \tilde{V}_p$); (c) Reduction in flux with coupling of MHD activity and edge plasma fluctuations.

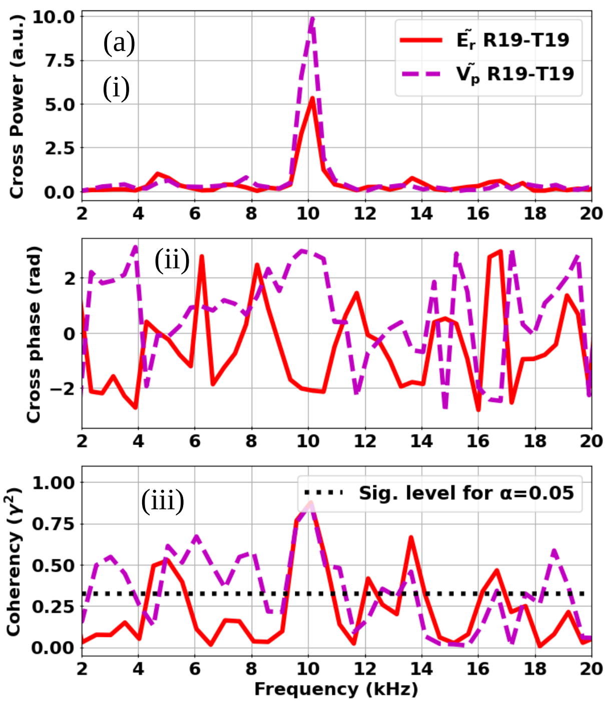
Theoretically modulation in potential perturbation due to a magnetic perturbation can be understood from the following relation:

$$\delta\phi(r) = -\left(\frac{\iota 4\pi v_A^2 l_s^2}{c^2\eta k_\theta^2}\right)^{\frac{1}{4}}\left(\frac{\omega-\omega^*}{\omega^2}\right)^{\frac{1}{4}} c\omega\delta A_\parallel^{(0)}\chi(z); where\ \delta A_\parallel = \ \ \delta A_\parallel^{(0)}$$

equation 35 and 36 of [3]. This suggests that a perturbation in the magnetic fluctuations will be reflected in the potential, conforming the excitation of m/n=2/1 mode structure in potential due to 2/1 MHD mode. However, for the coupling of even mode of potential to odd mode in density [4], the radial electric field should also be modified to induce a difference in poloidal velocity fluctuations i.e. $\tilde{V}_\theta = (\tilde{E}_r \times B_\phi)/B_\phi^2$. Introducing a compressibility associated with the toroidicity of the plasma, since $B_\phi \propto 1/R$, similarly to GAMs [5,6]. This condition holds provided that the time required to supress density accumulation due to $\tilde{V}_\theta$ is higher than the fluctuation time scale of the potential and density i.e. for higher frequency modes ~ 10 kHz for ADITYA-U tokamak. The modification of $\tilde{E}_r$ is studied to understand the underlying dynamics of the disparate mode structures observed in density and potential fluctuations in high-MHD activity regime.

It is observed that, in this regime, a frequency similar to the driver (MHD) frequency is dominant in the power spectral density of the $\tilde{E}_r$, exhibiting a mode structure of m/n=2/1 similarly to the potential fluctuations, as depicted in figure 2a. Furthermore, from figure 2b it is evident that the amplitude of the 2/1 oscillations in $\tilde{E}_r$ increases with the amplitude of the MHD activity, establishing the MHD-induced modification in $\tilde{E}_r$.

The characteristics of MHD-induced coherent mode, such as its oscillatory nature, disparate mode structures in density and potential, coupling of even mode of potential to odd mode in density, suppression of turbulence and reduction of associated transport are similar to those of geodesic acoustic modes (GAMs). However, while the conventional GAM is identified with m/n = 0/0 in potential and m/n=1/0 in density oscillations, the excitation of of GAMs with higher m/n is theoretically possible [4]. One particularly interesting feature of GAMs is the existence of global GAMs, where the GAM frequency is independent on the radial variation of local temperature i.e. invariant due to a change in radial location similarly to the MHD-induced coherent structure in ADITYA-U tokamak.



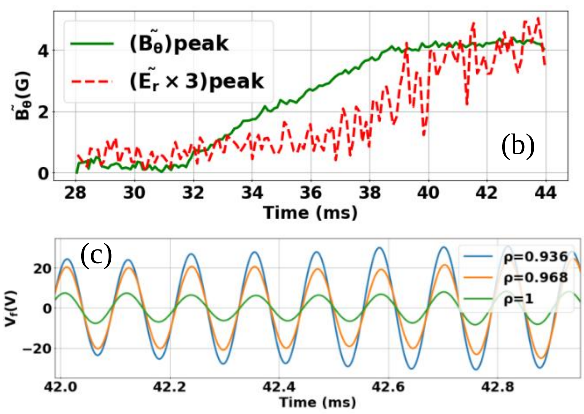


Figure 2: (a) Cross Power (i), Cross Phase (ii), and Coherency (iii) between poloidal separated measurements of radial electric field and potential fluctuations (b) Variation of radial electric field and 2/1 MHD mode amplitude
(c) Spatial (radial) variation potential fluctuations

Geodesic Acoustic Modes (GAMs) in tokamaks are primarily driven by turbulence-generated Reynolds stress and nonlinear interactions with drift-wave turbulence. These modes arise due to geodesic curvature effects in toroidal plasmas and play a crucial role in regulating turbulence and enhancing confinement by generating sheared flows that suppress turbulent transport. Their ability to mitigate turbulence and improve plasma stability makes them an essential component in optimizing fusion performance. The observation of MHD-induced coherent structures in the ADITYA-U tokamak shows characteristics of driven higher m/n global GAMs, including frequency entrainment, turbulence suppression, and distinct mode structures in potential and density. This suggests that similarly using external magnetic perturbations can drive GAMs, regulate edge plasma turbulence, and control transport processes.

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