GAM evolution in L-mode approaching the L-H transition on JET

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Introduction

The interaction between zonal flows (ZFs) and turbulence is a self-regulating mechanism. Understanding this interaction is crucial to control plasma confinement. The shearing due to ZFs is thought to dominate in regimes when the mean shear flow is modest as before and during the L-H transition [e.g. 1]. This was corroborated by findings in different devices demonstrating the importance of both the oscillating and mean flow shear and their interaction in triggering the transitions [1-4]. While on AUG the sheared flow below the L-H threshold is dominated by Geodesic Acoustic Modes (GAMs) [1], on devices such as DIII-D [2], EAST [3] and HL-2A [4] GAMs do not appear to be important on the way to H-mode. The reported results reveal that no clear picture exists on the relevance of GAMs in the turbulence collapse required for the formation of steep pressure gradients at the transition. This contribution focuses on the characterization of GAMs in JET plasmas when approaching the L-H transition aiming at understanding its possible role in triggering the transition.

Description of the experiment

Doppler backscattering (DBS) is a microwave diagnostic for density fluctuation measurements that measures the radially localized propagation velocity and fluctuation level of intermediate wavenumber turbulent structures. DBS has been used to investigate GAMs by measuring oscillations in the E × B flow velocity. This diagnostic has been used previously at JET to characterize GAMs [5], where a detailed description of the diagnostic together with an explanation of the GAM analysis method can be found.

GAM measurements have been obtained during a plasma current ($2.2 < I_p < 3.2$ MA) and line-averaged density ($1.6 < \bar{n} < 3.6\times10^{19}$ m^{-3}) scan in order to determine the underlying mechanisms that influence the L–H power threshold scaling. The dataset also includes variations in toroidal magnetic field, magnetic configuration and hydrogen isotopes. The L–H transitions were obtained by slowly increasing the NBI heating power.

Scaling of the GAM amplitude on $\bar{n}$ and I_p

Previous studies based on the ohmic phase of the discharges in the dataset demonstrated that parameters such as $\bar{n}$ and I_p have a strong effect on the GAM amplitude [6]. By assessing the importance of critical parameters such as safety factor and collisionality, experimental evidence is found for the different mechanisms determining the GAM amplitude: turbulence drive, collisional and collisionless damping. Evidence for collisional damping is only found at low I_p, high density discharges. For the remaining dataset, the GAM amplitude is well described by a balance between turbulence drive and collisionless damping.

Heating power dependence of the GAM amplitude

GAMs have been studied along the power ramp used to induce the L–H transition, taking advantage of the unique JET dataset. The temporal evolution the mean perpendicular velocity, normalized density fluctuation level and GAM amplitude for different probing frequencies is presented in figure 1 for a typical discharge with an L-H transition (#90484, I_p = 2.5 MA, B_T = 3 T, $\bar{n}$ = 3.2 × 10^{19} m^{-3}). Shortly after the NBI power is applied, the GAM amplitude is reduced decreasing further as the L-H transition is approached. Although the GAM amplitude is often observed to first increase with heating power, it is in general reduced before the L-H transition. The GAM amplitude near the transition is typically larger for high density discharges in agreement with previous observations revealing that the GAM amplitude tends to increase with density [5, 6].

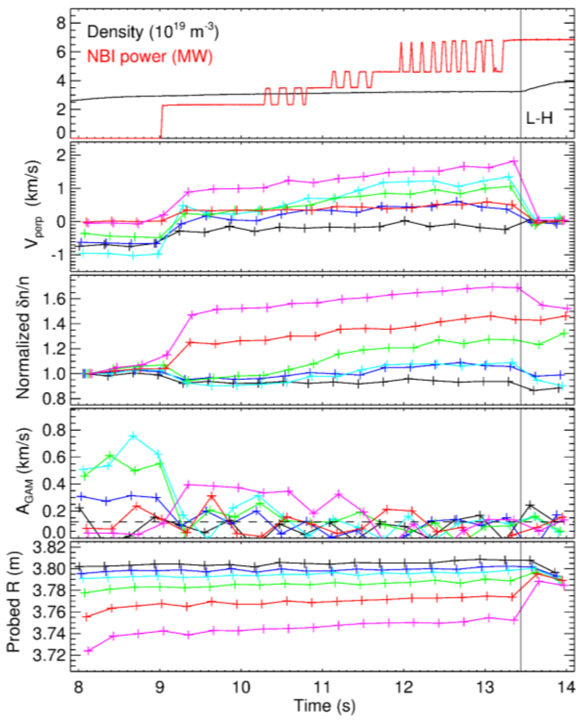

Figure 1: Temporal evolution of density and heating power (a), mean perpendicular velocity (b), normalized density fluctuation level (c) and GAM amplitude (d) for discharge #90484 for different probing frequencies (e).

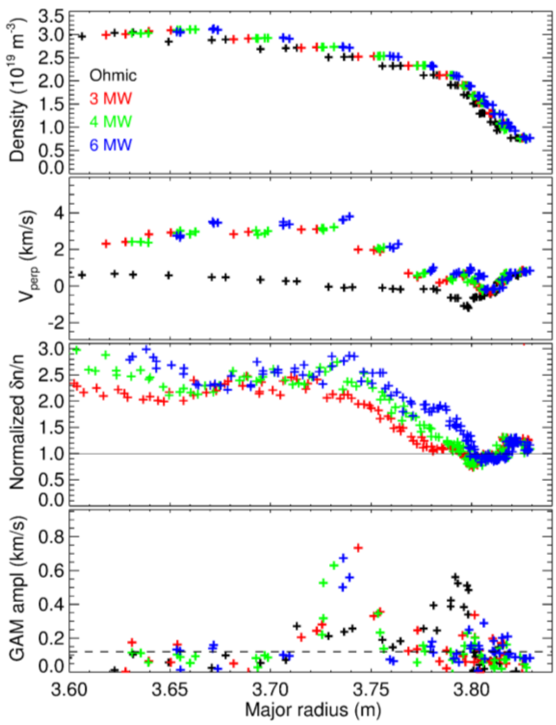

Figure 2: Radial profiles of density (a), mean perpendicular velocity (b), normalized density fluctuation level (c) and GAM amplitude (d) for discharge #90492 for different NBI power levels.

GAMs have either modest amplitude at the transition or are below detectable limits for the technique applied here. The cause of this decrease in the GAM amplitude may be related with the reduction of the turbulence levels in the region where GAMs are observed when the NBI power is applied possible due to changes in the plasma rotation profile induced by the NBI torque. However, changes in the density fluctuation levels are modest (~10%), with the ohmic values recovered later on along the heating power ramp. As the collisional damping rate is also expected be reduced along the power ramp, it is unclear why GAMs are not observed at a later L-mode phase of the discharge and why they are reduced before L-H the transition.

GAM radial location

Figure 2 displays the radial profiles of the mean perpendicular velocity, normalized density fluctuation level and GAM amplitude for discharge #90492 (I_p = 2.5 MA, B_T = 3 T, $\bar{n}$ = 3.6 × 10^{19} m^{-3}) with a higher line-averaged density compared to the discharge shown in figure 1. In this case, the GAM survives up to the L-H transition. As NBI heating is applied, the density fluctuation levels decreases slightly (~10%) in the steep gradient region, increasing significantly inside the pedestal top (factor of ~2). The equilibrium flow profile is clearly observed to move upward when the NBI power is applied but then exhibits a modest variation with the NBI power up to the transition.

During the ohmic phase, GAMs are generally most intense in the edge density gradient region near the pedestal top. As the heating power is ramped up, the GAM amplitude decreases near the pedestal top in the region where the fluctuations levels are reduced, appearing further inside in a region where density fluctuations increase. As the diagnostic is not absolutely calibrated, we can only compare variations with respect to reference measurements and therefore cannot conclude about the absolute fluctuations level at the different radial locations. Apart from changes in the turbulent drive the balance between the collisional and collisionless damping rates should also play a role in the radial variation of the GAM location, with damping rates having opposite trends with radius: collisional damping increases with radius, contrary to the collisionless damping rate. It is interesting to note that the GAM existence region does not appear to be continuous, moving from ρ ≈ 0.96 to ρ ≈ 0.93.

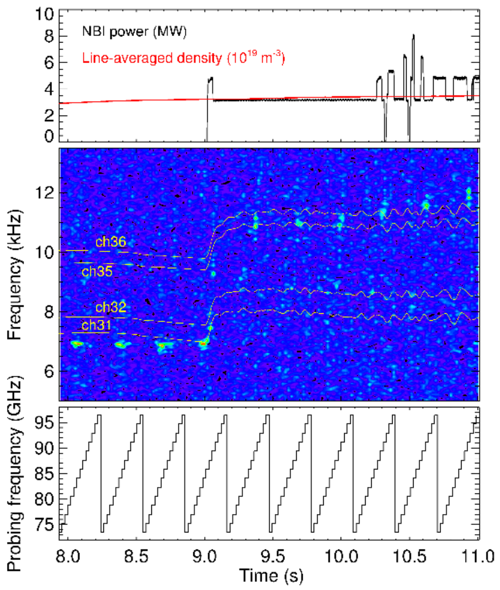

Figure 3: Temporal evolution of the density, heating power, spectrogram of the reflectometry Doppler shift and probing frequency for discharge #90492.

Figure 3 shows the temporal evolution of the line-averaged density, heating power and reflectometry probing frequency, together with the spectrogram of the Doppler shift. As illustrated, the frequency spectrum is sharply peaked at ~7 kHz during the ohmic phase. Shortly after the NBI power is applied the dominant GAM frequency shifts to ~11 kHz. Also shown in figure 3 (solid lines) is the calculated GAM frequency using the local temperature given by different ECE channels revealing that the evolution of main GAM frequency is not consistent with that of the local temperature at a single position but rather with the local frequency at two distinct radial location.

Coexisting GAMs of different frequencies have been observed with Langmuir probes in the edge plasma of HL-2A tokamak in low density Ohmic discharges [7]. The GAM was found to propagate both inward and outward with its frequency remaining the same during the process. The GAM structure at JET seems to be different. GAMs with different frequencies do not appear to coexist at the same radial locations contrary to HL-2A observations. The existence region of the GAMs with different frequency is separated by about 5 cm having a radial extension of about 2 cm. This suggests that GAMs are strongly damped with a decay length in the order of the cm, only existing in the region where they are generated. As the collisionality increases with radius the GAM outward propagation may be limited by collisional damping.

Discussion

In this work, the GAM and turbulence characteristics are measured at the plasma edge for different plasma current and line-averaged densities to investigate how they impact on the L–H transition. GAMs are found to have modest amplitude at the transition except for high density discharges. The large turbulence amplitude associated with the high density discharges may provide a stronger drive for GAMs. These observations suggest that the GAM is not responsible for facilitating the transition as the L-H power threshold also increases with density in the high density branch of the L-H transition.

Different reports have presented experimental evidence that the turbulence poloidal flow spectrum evolves from GAM mode dominant at lower power to low-frequency ZF dominant near the L–H transition associated with an increase of the effective shearing rate [2-4]. Although no significant change in the mean perpendicular velocity seems to occur preceding the transition, the temporal resolution of the measurements for each probing frequency is only ~300 ms for the diagnostic settings used in this experiment and therefore the fast dynamics near the transition cannot be studied. As ZFs have been identified at JET [8], a systematic study of the evolution of ZFs and GAMs as the L-H transition is approached should be performed with a suitable temporal resolution to assess a possible competition between ZFs and GAMs for the transfer of turbulent energy. Our results suggest that the GAM alone should not play a leading role for causing the L-H transition.

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