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Intermittency of density fluctuations and zonal flow generation in the MAST and ST40 spherical tokamaks

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Density fluctuations at the edge of a tokamak plasma exhibit intermittent behaviour due to presence of coherent structures, blobs and density holes. The spreading of holes and blobs from the plasma edge towards the core and scrape-off-layer can contribute to the non-local origin of transport. The dynamics of edge fluctuations are closely linked to interplay with zonal flows [1].

Evidence of the existence of large-scale, high-amplitude blobs and holes at $r/a = 0.8 - 1.1$ is presented using beam emission spectroscopy (BES) measurements on the MAST spherical tokamak. Analysis of similar L-mode discharges indicates that coherent structures are formed 2−4 cm inside the separatrix (Figure 1) [2]. After their formation, the density blobs and holes propagate radially outwards and inwards, respectively. A common mechanism sets the statistical properties of the density fluctuations across a radial region of 20 cm. An analysis of the poloidal velocities of the density fluctuations suggests the presence of low-frequency zonal flows and geodesic acoustic mode (GAM). Both the poloidal velocity and the density fluctuations exhibit bursty behaviour, with bursts in the density fluctuation power followed by quiescent periods featuring a transient increase in the GAM power. These experimental results appear to support a theoretical picture of turbulence in fusion plasmas dominated by coherent structures [3,4], with the growth of zonal flows alternating with the increase in turbulence power: zonal flows grow and suppress the fluctuations, but then decay in absence of turbulence, triggering another burst of fluctuations (a version of the predator-prey scenario).

Bispectral analysis confirmed the presence of nonlinear coupling between the GAM and the density-fluctuation field over a wide frequency range. The GAM frequency of 8 kHz was constant over a range of radii, demonstrating an eigenmode structure.

Analysis of the diverted L-mode plasmas and plasmas featuring the L-H transition using the magnetic probe and visible light diagnostics suggests the presence of GAMs in the high-field spherical tokamak ST40. A spectrogram of the time derivative of poloidal magnetic field, $\dot{B}_p$, reveals several modes with bursty dynamics (Figure 2). Observed three-wave interactions between the GAMs and broadband turbulent fluctuations support the non-linear nature of the modes. The existence of several modes attributed to the GAMs hints at an eigenmode structure of the modes, similar to the findings on MAST. Emergence of a coherent flow pattern at the edge of plasmas exhibiting structure formation that we report here is in line with the simulation results of magnetized plasmas near the marginal stability state [3,4].

References

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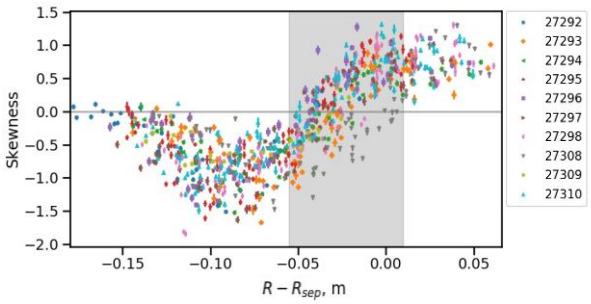

Figure 1. Skewness of density fluctuations in the MAST plasmas. Each colour and symbol represents a different plasma discharge. The grey band represent the region where skewness is close to zero.

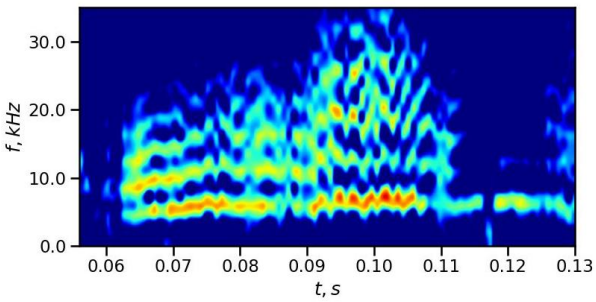

Figure 2. Spectrogram of $\dot{B}_p$ measured by the midplane magnetic probe at the HFS in the L-mode ST40 discharge #11582.

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