Interaction of GAM zonal flows, mean flows and edge turbulence across the L-H transition in ASDEX Upgrade

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A complex interaction between turbulence driven $E \times B$ zonal flow oscillations, i.e. geodesic acoustic modes (GAMs), mean equilibrium flows, and the turbulence is observed during the L-H confinement transition in the ASDEX Upgrade tokamak [1]. GAMs are readily observed in the L-mode edge where the turbulence appears to be moderated more by the oscillatory zonal velocity shearing rate rather than the weaker mean flow shear. The GAM behaviour across the transition to H-mode depends on the plasma density. At low density a limit-cycle oscillation (pulsation) forms below the L-H threshold, driven by a competition between the turbulence and an enhanced GAM flow shear suppression. This intermediate regime (labeled I-phase), where the GAM shearing rate exceeds the turbulence decorrelation rate, has an L-mode like edge (weak temperature pedestal) but improved energy confinement and a deeper average edge E_r well. With increasing heating power the I-phase evolves into an H-mode. As the mean flow shearing rate grows the pulsation duty-cycle falls until it becomes too short to sustain the GAM, which is replaced by large amplitude broadband flow perturbations. At this point the mean shear overtakes the GAM shearing, the edge turbulence is suppressed, the GAM disappears and clear H-mode pedestals form. During the evolution the E_r well deepens and moves inward, coinciding with a radial erosion of the GAM zonal width, i.e. the GAM exists only in the negative E_r shear region, highlighting the linkage between the zonal/GAM flows and the mean equilibrium flows. At higher densities both limit-cycle and GAM frequencies fall - the GAM due to reduced temperatures and the limit-cycle to zonal/collisional damping. In addition the stronger heating required by the higher power threshold may also drive the transition faster.

[1] G.D.Conway *et al.* Phys. Rev. Lett. **106**, 065001 (2011)