Study of Turbulence and Radial Electric Field Transitions in ASDEX Upgrade using Doppler Reflectometry

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The radial electric field is recognised as an important factor in the performance of magnetically confined fusion plasmas. On ASDEX Upgrade microwave Doppler reflectometry has been developed to directly measure $E_r$ profiles, its shear and its fluctuations. Here a poloidally tilted antenna selects via Bragg a specific turbulence wavenumber giving a frequency shift directly proportional to the perpendicular rotation velocity $u_\perp = v_{E \times B} + v_{\text{turb}}$ of the turbulence moving in the plasma. Turbulence simulations show $v_{E \times B} \gg v_{\text{turb}}$ allowing simple extraction of $E_r$ with good accuracy. In the scrape-off-layer $E_r$ is positive, but reverses across the separatrix due to the pedestal pressure gradient to form a negative well. The strength of the well scales directly with confinement, typically -50V/cm for ohmic/L-mode, rising to -300V/cm for H-mode and in excess of -500V/cm for improved H-modes. Without NBI $v_{E \times B} \approx v_{\text{turb}}$ which allows the turbulence behaviour to be investigated. For example the core rotation reverses from ion to electron direction when plasma collisionality is raised while matched gyro-kinetic turbulence simulations show the dominant turbulence changing from TEM to ITG with corresponding $v_{\text{turb}}$ reversal, which implies the core $E_r$ reverses sign with the turbulence. Also of major importance to confinement are zonal flows and GAMs - radially localised oscillating $E \times B$ flows. $E_r$ fluctuations directly measured by Doppler refl. reveal coherent modes in the edge gradient region where turbulence vorticity and $E_r$ shear are largest. The mode frequency scales as sound speed over major radius but is sensitive to plasma shape and local $q$. So far GAMs have not been seen in H-modes, nor in the plasma core. In each topic, the synergetic combination of experiment, theory and numerical simulation aids interpretation shows $E_r$ is interlinked with turbulence and the mean plasma profiles.