Analysis and prediction of momentum transport in spherical tokamaks

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The inward momentum convection or "pinch" observed in many tokamaks can be explained by the Coriolis drift mechanism, with relatively good quantitative agreement found with gyrokinetic predictions of the ion temperature gradient (ITG) instability. Here we attempt to validate this model over a broader range of beta and aspect ratio by extending into the spherical tokamak (ST) plasma regime using data from NSTX and MAST. Previous perturbative measurements in NSTX H-modes have indicated the existence of an inward momentum pinch with a magnitude similar to that observed in conventional aspect ratio tokamaks. However, linear gyrokinetic simulations run for these cases predict the microtearing mode, which only transports electron energy, is the dominant micro-instability in the region of interest due to the relatively large plasma beta (β_N=3.5-4.6). Although weaker, there is also evidence of a variety of unstable electrostatic and electromagnetic ballooning modes including ITG, compressional ballooning modes (CBM), and kinetic ballooning modes (KBM). Quasi-linear calculations for all of these ballooning modes, assuming they contribute substantially to the momentum transport, predict a pinch that is small or directed outward, in contradiction to the experimental results. Additional scans show that the weak pinch is a consequence of how both electromagnetic effects (at relatively large beta) and low aspect ratio influence symmetry-breaking of the instabilities. To minimize electromagnetic effects, similar experiments were performed in MAST L-mode plasmas at relatively low beta (β_N=2) using the time-dependent rotation response after the removal of a short n=3 applied magnetic field perturbation. The inferred inward pinch is similar in magnitude to conventional tokamaks and the NSTX H-modes. However, linear gyrokinetic simulations indicate that even for low beta L-modes the predicted momentum pinch is relatively small and cannot reproduce the large experimentally inferred pinch. Based on the above observations and simulations, the Coriolis pinch mechanism predicted from local, linear gyrokinetic theory does not appear to explain perturbative momentum transport at low aspect ratio. Other mechanisms neglected thus far are being investigated as possible solutions to the apparent discrepancy, including nonlinear effects, perpendicular E×B shear driven transport, centrifugal effects and profile shearing. This work is supported by US DOE contract DE-AC02-09CH11466 and the RCUK Energy Programme and EURATOM.