Neoclassical viscosity and rotation in stellarators. Simulation vs. experiment for the TJ-II stellarator.

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Sheared radial electric fields are generally accepted to play a central role in confinement transitions in fusion plasmas. In non-quasisymmetric stellarators, the long-wavelength component of the radial electric field is determined from the ambipolar condition of the neoclassical fluxes [1, 2]. The short-wavelength or zonal component is associated to turbulent phenomena. The latter is observed, in particular, close before confinement transitions (see e.g. [3]). In this talk, we discuss the extent to which turbulence can overcome the neoclassical viscosity and modify the $\mathbf{E}\times\mathbf{B}$ rotation through momentum transport.

With this purpose, we study low-density plasmas of the stellarator TJ-II. A spontaneous confinement transition takes place in this non-quasisymmetric stellarator when a critical density is reached [4]. This transition is associated with the change of sign of the long-wave-length radial electric field and the corresponding formation of a shear layer. Close before the transition, long-range correlated (LRCed), zonal-flow like electric potential structures emerge.

We first solve the drift kinetic equation for fixed or slowly varying, time-dependent profiles and show mean flows ($\mathbf{E}\times\mathbf{B}$ and bootstrap), measured by Charge-eXchange Spectroscopy on a shot-to-shot basis, that are correctly predicted by neoclassical theory [5]. We then show that also the calculated evolution of the mean radial electric field is in good agreement with the measurements by Heavy Ion Beam Probe in dedicated density ramp experiments. We finally provide, within the same framework, a fundamental explanation for a wealth of experimental observations in the neighbourhood of the critical density: the neoclassical viscosity, which acts as the restoring force of E_r deviations from ambipolarity, goes smoothly to zero when the critical density is approached, hence allowing for large E_r excursions and, in particular, low frequency LRCed potential fluctuations [6]. In order to complete the picture, we simulate the collisionless damping of zonal flows with the gyrokinetic code EUTERPE. Low frequency oscillations of the zonal potential are observed in qualitative agreement with experimental LRCs observations.

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