Investigations of the role of neoclassical transport on W7-X

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The role of the radial electric field in high performance ion-root plasmas on Wendelstein 7-X (W7-X) is examined and compared with neoclassical predictions. In stellarator plasmas the neoclassical radial electric field (E_r) is not intrinsically ambipolar, and is instead strongly tied to the plasma profiles. The properties of the E_r profile strongly influence neoclassical transport of heat, particle and impurities.

The W7-X stellarator is the world's first large scale optimized stellarator[1,2]. One of the important targets chosen for optimization during the W7-X design process was the reduction of core neoclassical heat transport[3]. This optimization was targeted for reactor relevant[4] high-density plasmas with $T_e \approx T_i$ in which the neoclassical ambipolar radial electric field is expected to negative throughout the plasmas core.

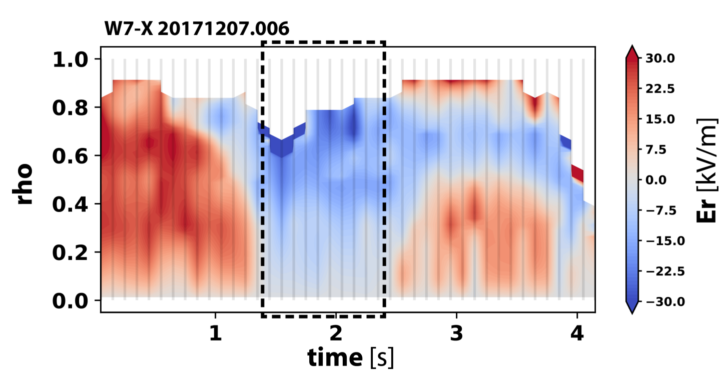

Figure 1. Inverted radial electric field as inferred from XICS measurements. Raw data has been binned prior to inversion to provide 100 ms time resolution and 3 cm spatial resolution. Vertical lines denote actual measurement times (center of integration window); color between lines is interpolated. The dashed box indicates the time window in which the plasma is fully within the ion-root regime.

Measurements of the core radial electric field (E_r) have confirmed that ion-root conditions (negative Er in the plasma core) have been achieved in W7-X with high-density plasmas and central ERCH heating. These measured Er profiles

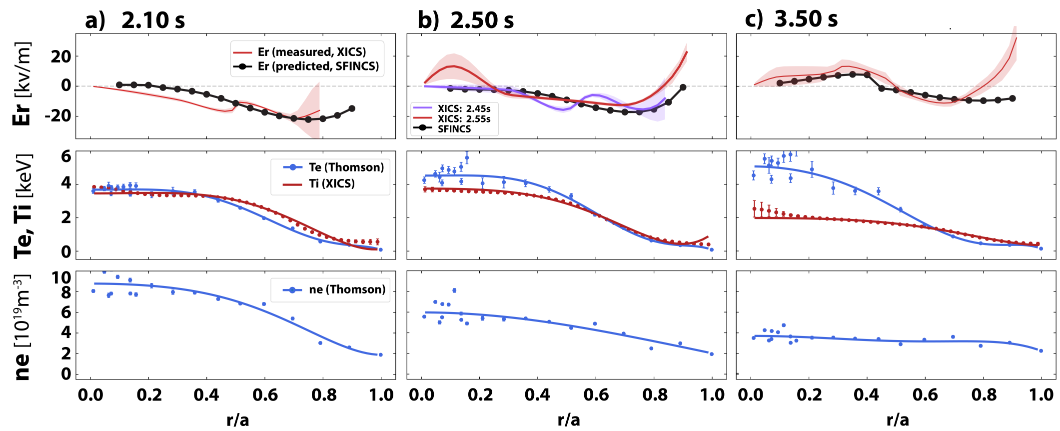

Figure 2. Temperature, density and radial electric field profiles from 20171207.006, shown at three different times.. (a) Peak density, ion-root conditions across full plasma minor radius and Ti≈Te; (b) Near transition density, electron root just developing in plasma core; (c) Low density, electron root in plasma core out to rho~0.5. In each case the experimental measurements of the radial electric field from XICS are compared with neoclassical calculations from SFINCS.

agree well with the neoclassical ambipolar Er predicted by the code SFINCS[5]. This good agreement provides confidence in the validity of neoclassical calculations in high-density ion-root conditions, and enables initial studies on the role of neoclassical transport in the optimized high-density regime of W7-X.

During the first W7-X experimental campaigns a set of dedicated experiments have been completed to study core heat transport over a range of plasma conditions and radial electric fields. In these experiments gas fueling has been utilized to achieve steady state conditions with central densities in the range of 1.0x10^{19}m^{-3} to 1.2x10^{20}m^{-3} and total stored energies up to 0.8MJ. In addition, pellet fueling has been utilized to transiently achieve even higher stored energies, up to 1.2MJ. Finally, experiments with off-axis heating have been used to explore the effect of profile shaping and to achieve ion-root conditions in a range of moderate plasma densities.

Select plasmas from this set of experiments have been examined in detail to understand the conditions required for access to the ion-root. Experimental radial electric field profiles are inferred from the perpendicular velocity[6] ($u_\perp$), as measured by the XICS diagnostic, and available with a high time resolution of up to 10ms. These diagnostic measurements provide the detailed profile evolution of the radial electric field in response to changes to the plasma density and heating power.

Profile measurements[7] of electron temperature (T_e), ion temperature (T_i) and electron density (n_e) along with approximations for the average value of Z_{eff} have been used as inputs to the SFINCS[5] code to calculate the ambipolar E_r profile along with neoclassical ion and electron heat flux profiles (Q_i, Q_e). Finally the total experimental energy input to the electrons and ions, from ECRH heating and collisional heat transfer, has been compared to the neoclassical heat fluxes to provide a first estimate for the fraction of transport that can be attributed to neoclassical processes in reactor relevant high-density ion-root conditions.

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