Appendix — XGC0 Neoclassical Ion Transport Calculations for QH-mode – D. Battaglia

1.0 Introduction

The goal of the work described below is to begin testing whether neoclassical ion transport plays a significant role in the physics controlling the particle transport in the edge pedestal plasma under QH-mode operation. For the work described here the XGC0 Particle-in-Cell (PIC) code was used to simulate a QH-mode plasma shot from DIII-D and compare the calculated neo-classical ion transport to experimental measurements.

XGC0 is a code that leverages high-performance computing to calculate the self-consistent full-f drift-kinetic solution for ion transport in the H-mode pedestal using a realistic diverted magnetic geometry and Monte Carlo neutral recycling model. The large computational resources required to solve the full-f solution is justified on the observation that kinetic ion effects (such as ion orbit loss and finite orbit effects) have significant impacts on the ion thermal, particle and momentum transport in the H-mode pedestal and scrape-off layer.

The code was recently updated to enable quantitative comparison to experimental measurements in order to evaluate the role of axisymmetric neoclassical transport in various H-mode transport regimes. These updates include: (1) addition of impurity ions to the simulation since most ion diagnostics measure the properties of plasma impurities, (2) synthetic diagnostics for typical profile diagnostics on NSTX and DIII-D, such as charge-exchange spectroscopy and Thomson scattering, and (3) improved code diagnostics that track the contributions of different transport processes on the energy, particle and momentum balance.

The ability to quantitatively compare the simulation to experimental measurements has enabled XGC0 to be used as an interpretative transport model. Ad-hoc anomalous transport is added to the neoclassical transport level if it is needed to improve the agreement between the simulation and experimental measurements.

2.0 QH-mode

Interpretative XGC0 was used to investigate the neoclassical ion transport in a steady-state counter-injection QH-mode discharge that obtained high-spatial-resolution edge pedestal measurements using an outboard edge sweep (discharge 106999).

Large anomalous particle, energy and momentum transport (~1 m^2/s) is required from the inner boundary of the simulation to the top of the pedestal ($\psi_N < 0.94$), suggestive of ion-scale turbulent transport (Fig. B-1). The requirement of large anomalous transport levels in the region of shallow gradients at the top of the pedestal is consistent with XGC0 simulations of DIII-D H-mode pedestals.

The unique observation from this QH-mode simulation compared to H-mode simulations is that an anomalous co-I_p torque of about 0.5 Nm is required from 0.93 < ψ_N < 0.96 (inside edge of E_r well). This region corresponds to the location of the maximum EHO oscillations as determined from experimental measurements. The NTV-like induced drag on the counter rotation drives E_r positive and increases the neoclassical ion particle transport (where the impact on the particle transport rate increases with the ion charge) by reducing the "potential cliff" the ions encounter as they move radially outward through the pedestal. The increase in the neoclassical particle transport reduces the density gradient (especially the impurity density gradient) at the top of the pedestal and may provide a mechanism for regulating the pedestal pressure at the peeling-ballooning stability limit.

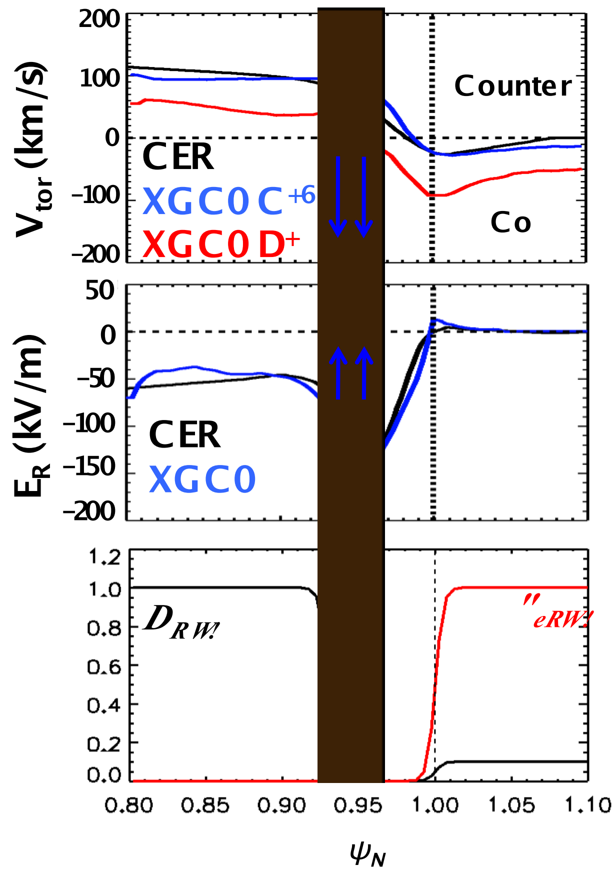

Fig. B-1. (Top) Simulated ion toroidal flows at the outboard midplane (red and blue) compared to the experimental measurement for C^{+6} (black). (Middle) XGC0 simulated E_r at the outboard midplane (blue) compared to the experimental measurement (black). (Bottom) Anomalous particle (black) and electron thermal (red) transport random walk (RW) added to the neoclassical transport in the simulation. Yellow shaded box indicates the region where 0.5 Nm of co-I_p torque is applied to improve the agreement between the simulated profiles and the experimental measurements.

3.0 Conclusions

The work with XGC0 has indicated that the local change in rotation, transport and the radial electric field induced by the EHO at the top of the pedestal can reduce the global particle confinement, especially impurity confinement. It also has indicated that the modification of the neoclassical transport in the pedestal by the EHO reduces the pressure gradient and bootstrap current, contributing to the mechanisms that regulate the growth of the peeling instability.

Reference

Chang, C.S., Ku, S., and Weitzner, H., Phys. Plasmas **11**, 2649 (2004).