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Self-Consistent Predictive Core-Pedestal ITER Scenario Modeling

T. Rafiq and J. Weiland

Mechanical Engineering and Mechanics, Lehigh University, Bethlehem, PA, USA

rafiq@lehigh.edu

ABSTRACT

- The dependence of fusion power production, temperature and density pedestals, and core profiles on varying q, edge density fueling strength, neoclassical transport, B-field strength, and α-heating are examined.
- The large edge q tends to provide hollow density while small edge q gives normal density profile.
- The rise in the source of the edge particle increases the density of the edge and the reaction rate close to the edge increases temperature fluxes, resulting in weak pedestal barriers.
- The pronounced edge barriers are identified when neoclassical transport is turned off or the B-field is increased
- The slope of the H-mode pedestal is found to be reduced due to α-heating.

BACKGROUND

- The purpose of these integrated ITER simulations is to identify dependencies that can impact the performance of ITER.
- Amortized cost of each ITER discharge (each 500 second experiment) would be approximately $1M, integrated simulations are important for preparing experimental campaigns, controlling the operation of ITER, and evaluating the effects of experiments.
- Self-consistent predictive core-pedestal ITER scenario modeling is carried out to simulate the time evolution of the plasma profiles and to optimize the performance of discharges.

CHALLENGES / METHODS / IMPLEMENTATION

PREDICTIVE INTEGRATED MODELING

- Goal: Reliable, validated, self-consistent predictions of evolution of plasma profiles from the plasma edge to the magnetic axis
- It is impractical to compute transport directly from gyrokinetic codes during each step of a integrated modeling simulation for the entire duration of a tokamak discharge, which is tens to hundreds of seconds.
- Simulation on a discharge time scale requires the development of physics based reduced models to describe anomalous transport

METHODOLOGY FOR SIMULATIONS

- The Weiland model is used to describe thermal, particle, and momentum anomalous transport results from turbulence
- Contribution from anomalous transport combines neoclassical transport computed using Chang-Hinton model
- Simulations begin with prescribed sources and an assumed L-mode profile and evolve to L-H transition and pedestal temperature and density
- No assumptions in the simulations that suggest that there would be an L-H transition or where temperature and density barriers should be located
- Alpha heating is determined using an analytical formula as per local density and temperature
- Impurity temperature is assumed equal to ion temperature
- Edge particle source is assumed to be Gaussian in space
- Transport due to fast particles and atomic physics is not included
- Toroidal rotation is thought to be minimal and is ignored
- Evolution of electron and ion temperature, electron density, poloidal rotation, $\boldsymbol{E} \times \boldsymbol{B}$ flow shear profiles, and fusion power are computed from separatrix to the magnetic axis

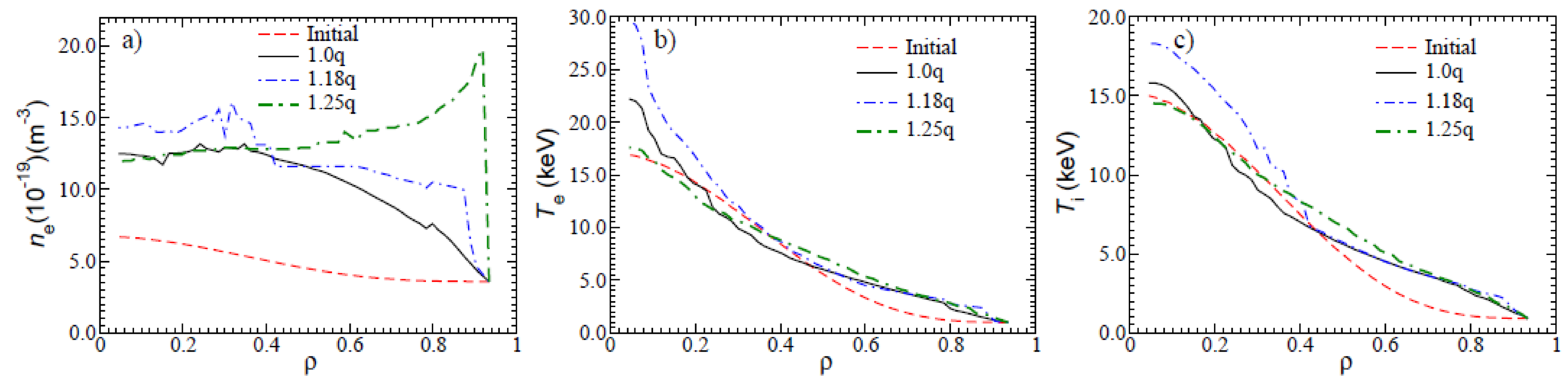
WEILAND ANOMALOUS TRANSPORT MODEL INCLUDES

- ITG, TEM, KBM, PB, collisionless and collision dominated MHD modes
- Effects of $\boldsymbol{E}\times\boldsymbol{B}$ shear, Shafranov shift stabilization, finite beta, impurity dilution, diffusion and radial convective pinch of toroidal and poloidal angular momentum
- Drift wave correlation length in the core and MHD type in the edge
- Eigenvalues and eigenvectors are computed; quasi-linear estimates are used for computation of all the transport coefficients

SIMULATION RESULTS

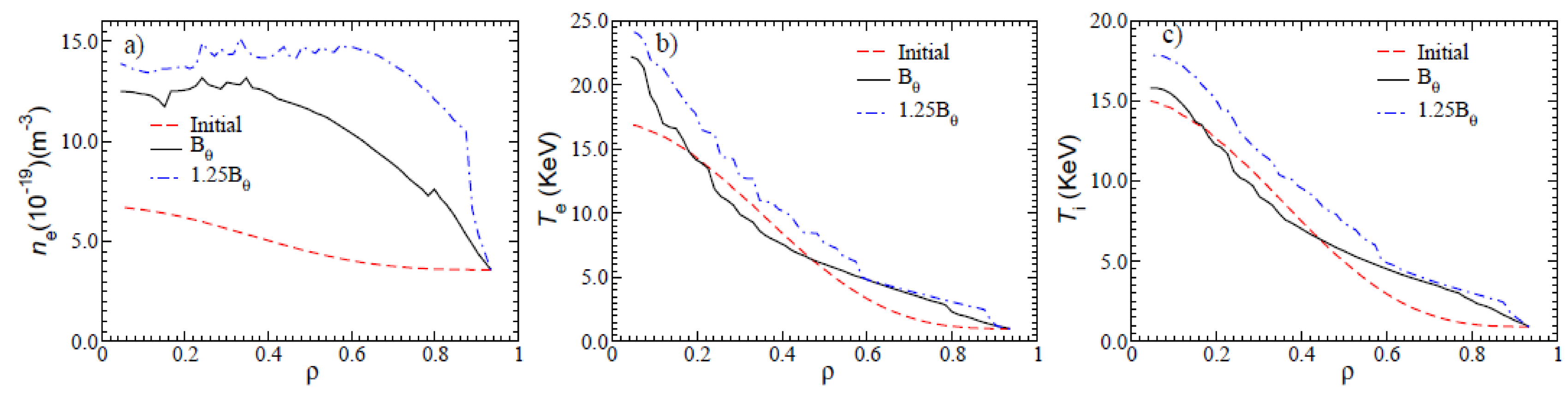
EFFECTS OF DECREASING q ON PLASMA PROFILES

It is found that large edge q tends to give hollow density while small q gives normal density profile. It is consistent with the result that $n \sim 1/q$. Note that higher q gives stronger ballooning instability and thus larger heat and particle transport, resulting in lower central density and temperature.



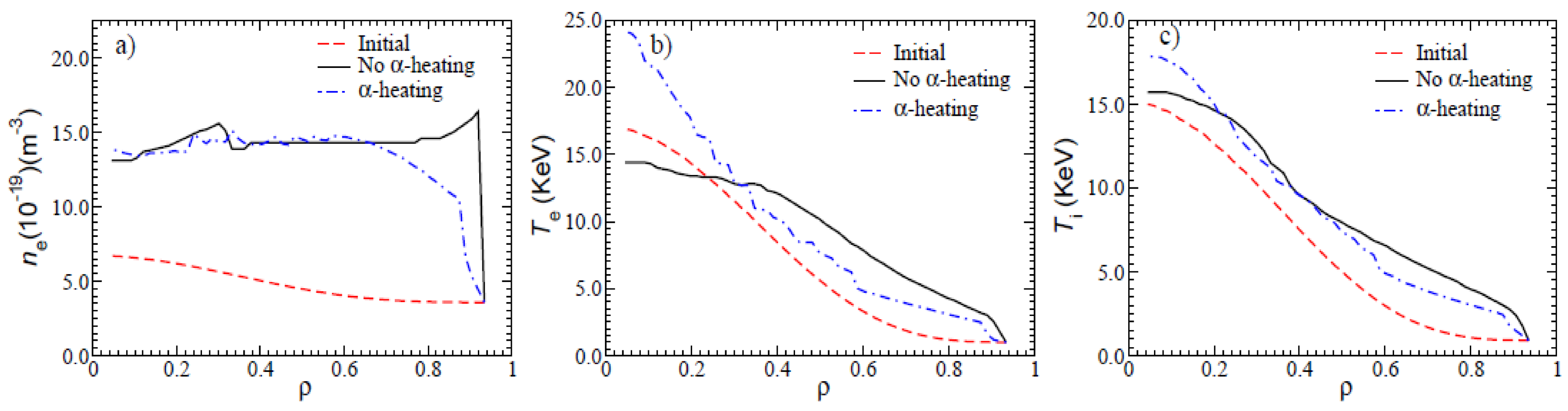
EFFECTS OF INCREASING B-FIELD ON PLASMA PROFILES

When the B-field is increased, the flatter density profile and pronounced edge barriers both in density and in electron and ion temperature are found. The distinct effects are due to increased B-field on MHD modes at the edge.



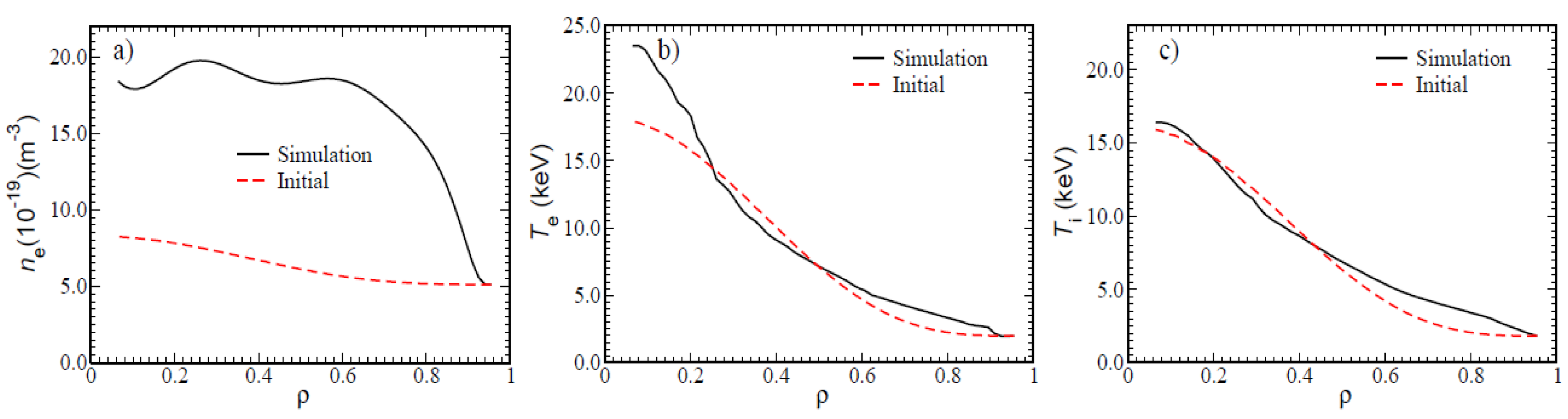
EFFECTS OF ALPHA HEATING ON PLASMA PROFILES

The temperature pedestal height and slope decrease in the presence of α-heating. Due to the stronger source of α, the electron temperature is higher than the ion temperature in the core, but the overall heat flux at the separatrix is the same.



EFFECTS OF INCREASING OF EDGE DENSITY SOURCE ON PLASMA PROFILES

There are two effects of increasing the edge particle source. First, it raises the edge density, and second, it increases the rate of reaction at the plasma's edge. As a consequence, temperature fluxes increase, resulting in weak pedestal temperature barriers.



CONCLUSION

- Large edge q tends to give hollow density while small edge q gives normal density profile. This is consistent with the result that $\boldsymbol{n \sim 1/q}$.
- Pronounced edge barriers are found when B-field is increased or neoclassical transport is turned off.
- Alpha heating is found to reduce the slope of the H-mode pedestal that can ease the problem of ELMs causing damage to the first wall.
- Increased edge particle source increases edge density and reaction rate near the edge, resulting in increased temperature fluxes and weak pedestals.

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