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Transport Barriers in Bootstrap Driven Tokamaks[1]

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Maximizing the bootstrap current in a tokamak, so that it drives a high fraction of the total current, reduces the external power required to drive current by other means. Improved energy confinement, relative to empirical scaling laws, enables a reactor to more fully take advantage of the bootstrap driven tokamak. Experiments have demonstrated improved energy confinement due to the spontaneous formation of an internal transport barrier in high bootstrap fraction discharges. Gyrokinetic analysis, and quasilinear predictive modeling, demonstrates that the observed transport barrier is due to the suppression of turbulence primarily due to the large Shafranov shift. ExB velocity shear does not play a significant role in the transport barrier due to the high safety factor. It will be shown, that the Shafranov shift can produce a bifurcation to improved confinement in regions of positive magnetic shear or a continuous reduction in transport for weak or negative magnetic shear. Operation at high safety factor lowers the pressure gradient threshold for the Shafranov shift driven barrier formation. The ion energy transport is reduced to neoclassical and electron energy and particle transport is reduced, but still turbulent, within the barrier. Deeper into the plasma, very large levels of electron transport are observed. The observed electron temperature profile is shown to be close to the threshold for the electron temperature gradient (ETG) mode. A large ETG driven energy transport is qualitatively consistent with recent multi-scale gyrokinetic simulations showing that reducing the ion scale turbulence can lead to large increase in the electron scale transport. A new saturation model for the quasilinear TGLF transport code, that fits these multi-scale gyrokinetic simulations, can match the data if the impact of zonal flow mixing on the ETG modes is reduced at high safety factor.

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