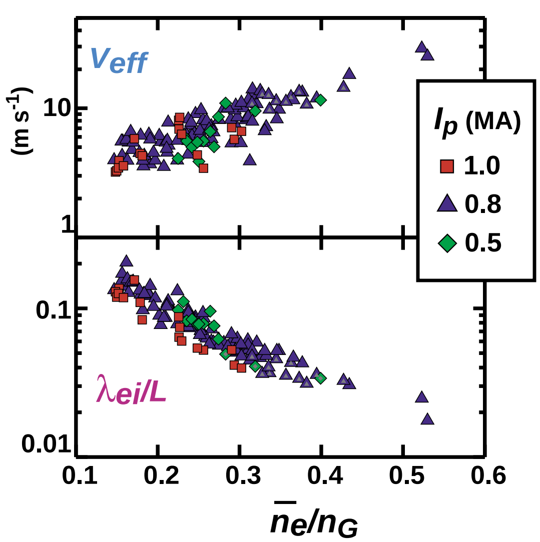
Edge Plasma Turbulence Implicated in Density Limit Physics

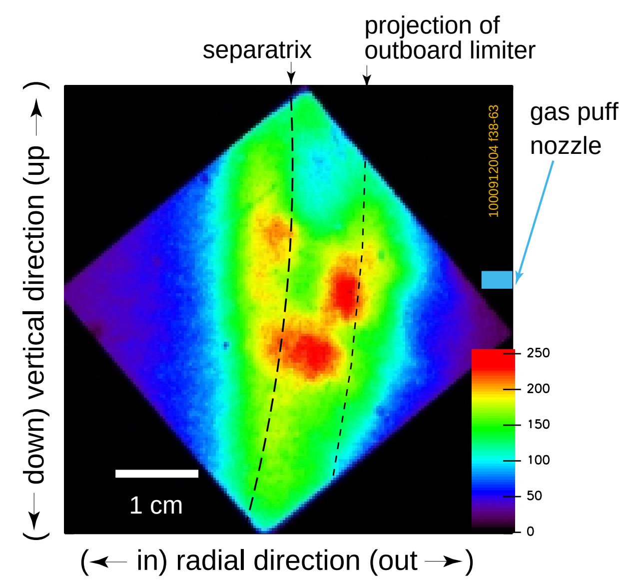
Edge plasma turbulence and associated heat convection losses are found to grow with discharge density, setting an operational limit.

Experiments on the Alcator C-Mod tokamak have shed new light on mechanisms which determine the maximum density that can be obtained in a magnetic confinement device. The maximum density, or 'density limit,' is one of the fundamental operational boundaries seen in magnetic confinement experiments. Since performance depends critically on the density of the fuel, fusion reactor designs are often required to operate near the boundary. As the boundary is crossed in tokamak devices, the edge plasma temperature drops and the plasma is abruptly terminated by a macroscopic magnetized-fluid (MHD) instability. Based purely on experimental observations, the density limit can be described by a simple and robust empirical scaling equation ($n_G = I_P / \pi a^2$, where the density, n_G is measured in 10^{20} m^{-3}, plasma current, I_P is in MA, and the minor radius, a is in m.) The physical mechanism which leads to this scaling is the subject of active research.

Recent experiments in Alcator C-Mod have uncovered a direct link between the character and scaling of cross-field particle transport in the edge plasma and the density limit boundary. As the density is raised, the edge plasma becomes more collisional; that is, the distance electrons travel between collisions divided by the magnetic field line length, λ_{ei} / L, is reduced. At the same time, the convective loss of plasma across field lines increases. At high density, the losses become strong enough to cool the plasma edge, thereby further increasing the transport. Associated with the onset of increased loss is a clear change in the edge plasma turbulence. At densities well below the limit, the plasma near the boundary (separatrix) is characterized by moderate-frequency turbulence (on the order of a few hundred kHz with turbulent-eddy lifetimes of a few microseconds). As the density is increased, a regime of fluctuations characterized by large amplitudes and long eddy lifetimes is observed to move inward, crossing the separatrix and intruding into the main plasma as the limit is reached.



As plasma density is increased, plasma convection (V_{eff}) increases dramatically while the plasma becomes more collisional (λ_{ei}/L decreasing).



Edge plasma fluctuations (as imaged by a fast camera system viewing a gas-puff) grow in amplitude and extent, reaching into the main plasma as the density limit is reached.

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