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On How Edge Shear Layer Collapse Defines Greenwald limit $n_g \sim I_p$

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We elucidate the physics of edge shear layer collapse and consequential emergence of the density limit phenomenology. While density limit is often associated with Marfes, tearing modes etc., it has long been appreciated that the density limit is also determined by the physics of particle transport. The edge shear layer ultimately regulates the particle transport. This work[1] presents a theory of edge shear layer collapse for $n \to n_g$, the Greenwald density limit[2]. Zonal flow screening is one of the key factors fixing strength of zonal flow shear. Favorable poloidal magnetic field (B_θ) scaling of zonal flow screening persists in the plateau regime, which is the relevant edge collisionality regime for modern tokamaks. This (B_θ) dependence is the ultimate origin of current scaling of the density limit. A novel predator - prey model with neoclassical screening and zonal/polarization noise[3] due to incoherent mode coupling yields the threshold condition for edge shear layer collapse, which is linked to a *critical value of the dimensionless parameter* $\rho_s/\sqrt{\rho_{sc}L_n}$. Here, ρ_s is ion sound radius, ρ_{sc} is screening length and L_n is density scale length. Zonal flows collapse when $\rho_s/\sqrt{\rho_{sc}L_n}$ falls below a critical value, determined by the zonal flow damping rate, turbulence nonlinear damping rate, triad interaction time and adiabaticity parameter. Thus, $\rho_s/\sqrt{\rho_{sc}L_n}$ emerges as the key dimensionless (i.e., physics) parameter which underpins the density limit $n_g \sim I_p$. *Smaller* ρ_{sc} *i.e., higher* B_θ *expands the regime of zonal flow persistence*. Zonal flows collapse when the integrated particle source S falls below a critical value $S_c \sim B_\theta^{-3}$. That means the particle source, required to hold the shear layer, decreases with increasing current. The limiting initial edge density for shear layer collapse scales favorably with plasma current. In a viscosity dominated regime, the critical edge density $n_c \sim S^{1/3}B_\theta$, whereas in charge exchange friction dominated regime $n_c \sim S^{2/3}B_\theta^2$. This novel theory of shear layer collapse, in contrast to the earlier work[4], applies to the adiabatic regime which is relevant for present day tokamaks.

Zonal shear collapse, beyond $n > n_c$, can lead to edge cooling by a sequence of shear layer collapse → increased edge transport → edge cooling → onset of radiative condensation and/or radiation induced island growth. In this scenario, the radiative cooling is secondary (i.e., a consequence of) to the transport bifurcation. Thus, a transport bifurcation -i.e., edge shear layer collapse may trigger undesired macroscopic phenomena in the discharge, as schematized in Figure 1. These results encapsulate the key transport physics underpinning the Greenwald limit. Results will be discussed in light of density limit and Ohmic phenomenology[5].

References
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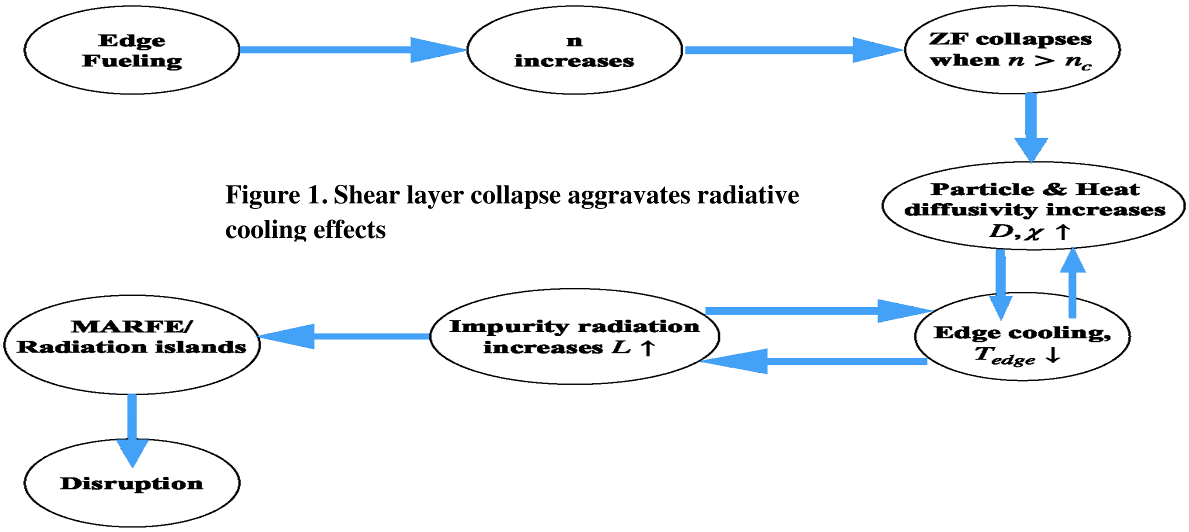

Figure 1. Shear layer collapse aggravates radiative cooling effects