The Greenwald density limit as a convective cell and radiative phenomenon in Reversed Field Pinch

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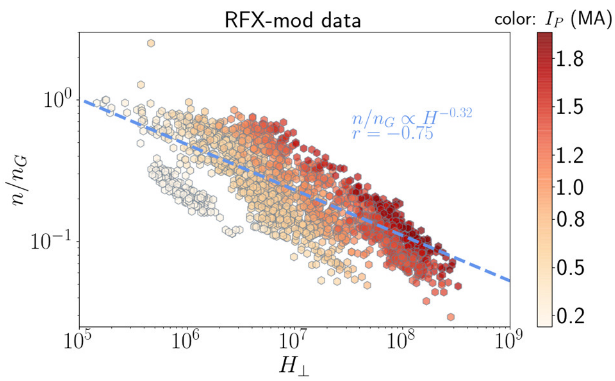
The Greenwald density limit is a phenomenological limit that restricts the achievable density in a thermonuclear fusion device. This is a longstanding issue for research in this field, since density appears in the figure of merit defining the efficiency of the future fusion reactor, namely the triple product $n\tau T$. Despite this importance, the density limit defies a unified, convincing theoretical explanation. Recently a series of papers [1,2,3] point out the role of a combination of radiative collapse and magnetohydrodynamic (MHD) instabilities resonating in the edge plasma, in determining the limit.

In the reversed field pinch (RFP), increasing density destabilizes the peculiar magnetic islands chain with poloidal symmetry located at the reversal radius. Such instabilities are responsible for the development of a multifaceted asymmetric radiation from the edge (MARFE), appearing at around half the Greenwald density n_G, corresponding to a local imbalance of input and radiated power. The radiated power is strongly driven by an increase of density in the MARFE region: it is shown that the destabilized magnetic islands generate convective cells via an ambipolar mechanism: in fact, an electrostatic potential (and the associated $\boldsymbol{E}\times\boldsymbol{B}$ flow) develops, with the same symmetry as the parent island. The convective cell accumulates density locally, in a poloidal annulus, which ultimately undergoes radiative collapse. In fact it is found that the amplitude of the $\boldsymbol{E}\times\boldsymbol{B}$ flow is directly proportional to the amplitude of the island with toroidal wave number $n=1$, showing that the pathological condition at large Greenwald fraction is determined by a critical size of the island. Since MHD determines the islands size, the limit itself can be related to the MHD relevant dimensionless parameters.

A discussion of the role of the first-principle based dimensionless Hartmann number $H=(\eta\nu)^{-0.5}\propto B^2T/n_e$, with η,ν plasma dimensionless resistivity and perpendicular viscosity will be presented. In fact, the Hartmann number rules the amplitude of the edge magnetic islands, both in 3D nonlinear viscoresistive MHD simulations [4,5] and in RFX-mod experiments: when H decreases below a first critical value H_{c1} (i.e. density increases), magnetic islands widen over a threshold, inducing the edge strong localized increase of radiation. If the size of magnetic islands widens even more, i.e. the Hartmann number H continues decreasing toward a second critical value H_{c2}, the RFX-mod plasma is difficult to manage, the density approaches n_G and MHD foresees a phase-transition of the plasma towards a stationary 2D state. In this sense the Greenwald parameter can be interpreted as the Hartmann number itself.

Furthermore, in 3D nonlinear MHD simulations of the RFP the decrease of H towards H_{c2} causes the already discussed increase of fluctuations of magnetic fields and a decrease of the shear of the poloidal flow at mid-radius, a fact that may be relevant in the density limit phenomenology.



1. In RFX-mod a clear relation between the first-principle MHD dimensionless Hartmann number H (here computed using the perpendicular Braginskij plasma viscosity) and the Greenwald density n_G is found.

References:

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