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Turbulence, Radiative Condensation and the Density Limit

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Any ignition experiment will likely occur at high density. Thus, there is renewed, intense interest in density limits and the physics underlying them. The critical issues in this area now have evolved to:

i) Is there a unique 'density limit' or are there separate limits on edge and core densities?
ii) What is the power scaling dependence of the density limit — and what is the physics underlying it?
iii) What physical process underpins the dramatic increase in transport and turbulence at the density limit? There is consensus that the onset of enhanced transport occurs when the edge turbulence transitions from adiabatic to hydrodynamic, as edge temperature drops and the edge density increases (1, 2). However, it's not clear what triggers this transition.

In this combined theoretical and experimental work, we report on progress in understanding the issues above.

Recent experiments (3, 4) in negative triangularity (NT) plasmas indicate:

i) a clear power scaling of the edge and core density, which differ. At high power (~13 MW), the density reaches roughly 2x Greenwald, and not all discharges are limited by disruption.
ii) the physics of the edge density limit is intimately connected to the MARFE, while the core density limit is enforced by the onset of apparent density avalanching.
iii) enhanced edge turbulence and transport **follows** the onset of the radiation and the MARFE. This suggests that radiative condensation cools the edge, raises the local density and thus initiates the evolution toward a hydrodynamic state of turbulence. Items (i), (ii) and (iii) here call out the need to study the interaction of radiative condensation with edge turbulence.

Theoretical work focuses on extending an existing model of power dependence to include radiative condensation. A key parameter emerges, namely the ratio of the radiative cooling rate to the turbulent edge transport rate. This ratio is analogous to the Damkohler number (5), familiar from combustion theory. A scenario emerges where increasing the density → increases the radiative condensation rate → thus increasing the radiative Damkohler number and → cooling the edge. This triggers a transition to hydrodynamic turbulence. The radiative Damkohler number then drops as the particle transport surges. Note that there are **two** mechanisms for power scaling, namely edge heat flux vs. radiative cooling, and edge heat flux drive of shear flows, which competes with collisional damping. **Both** enter the power scalings, at different stages of the evolution.

Ongoing work focuses on exercising the model and on consideration of the density limit mechanism in a burning plasma.

References

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