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Correlation of the tokamak density limit with edge collisionality

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A novel database study of the L-mode Density Limit (LDL) in metal- and carbon-wall devices (Alcator C-Mod, AUG, DIII-D, and TCV) identifies a two-variable, dimensionless stability boundary that predicts the LDL with significantly higher accuracy than the widely-utilized Greenwald limit. Historically, there has been broad interest in understanding the operational boundary imposed by the disruptive LDL because density is a critical lever for fusion performance. In this study, we create a multi-machine database of over 150 LDL events with 3000+ non-LDL discharges for evaluating the True and False Positive Rate. We find that data-driven models involving edge density and temperature measurements achieve significantly higher LDL prediction performance than the Greenwald fraction. Additionally, we utilize a Support Vector Machine to identify an analytic, dimensionless, stability boundary that retains the accuracy of the more sophisticated models, such as a Neural Network and Random Forest. The boundary is dominated by the effective collisionality in the plasma edge, $\nu_{*,\mathrm{edge}}$. This finding suggests that burning plasmas, with naturally low edge collisionality due to self-heating, may be able to achieve super-Greenwald densities. Additionally, in current and "next step" devices such as ITER, this collisionality boundary can also be deployed for active density limit avoidance.

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