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Strong Reversal of Simple Isotope Scaling Laws in Tokamak Edge Turbulence[1]

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The role of the nonadiabatic electron drive in regulating the hydrogenic isotope mass scaling of gyrokinetic turbulence in tokamaks is assessed in the transition from ion-dominated core transport regimes to electron-dominated edge transport regimes. Experiments often show confinement improving with increasing ion mass. However, simple gyroBohm-scaling theoretical arguments (that ignore electron dynamics) predict that the turbulent ion energy flux scales with the square root of the ion mass, implying that the global confinement degrades with increasing ion mass. Using nonlinear gyrokinetic simulations of DIII-D, we illustrate a remarkable transition in the turbulent isotope scaling towards the plasma L-mode edge. The transition is controlled by finite electron-to-ion mass-ratio dependence of the nonadiabatic electron response, dominantly generated by the parallel motion, which represents a correction to bounce-averaging of the electrons. The nonadiabatic electron drive strongly regulates the turbulence levels and plays a key role in favorably altering – and in the case of the DIII-D edge, reversing – the simple gyroBohm scaling. A novel isotope mass scaling law is proposed which describes the electron-to-ion mass ratio dependence of the turbulent energy flux and reversal from naive gyroBohm scaling in the edge. The finite electron-mass correction is larger for light ions and higher safety factor so that, while it is weak in the core, it dominates the mass scaling in the edge. These results may have favorable implications for global energy confinement and for the power threshold for the L to H mode transition in a reactor like ITER from hydrogen to deuterium to deuterium-tritium, consistent with recent experimental observations.

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