Improving the Isotope Scaling of Quasilinear Transport Models

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As fusion experiments transition from pure deuterium discharges to a mixture of deuterium and tritium, the ability to accurately predict the confinement properties of tokamak plasmas in different isotopes is becoming increasingly crucial. The gyroBohm scaling prediction that results from simple dimensional analysis suggests that the turbulent heat flux should increase with the square root of the isotope mass. However, it has long been observed in experiment and nonlinear gyrokinetic simulations that this scaling is not followed, in some cases even producing a decrease in flux as isotope mass is increased [1]. This 'isotope effect' remains an unsolved problem in transport physics. The quasilinear turbulence models used in integrated modelling suites to predict transport typically do not recreate this observed isotope scaling, due to their relative simplicity and historical focus on pure deuterium plasmas. This work aims to improve the predictive capabilities of quasilinear models in different isotopes. Via comparisons to nonlinear gyrokinetic spectra obtained from the code CGYRO [2], it is shown that the non-trivial isotope scaling originates primarily in the saturated potentials of the turbulence, specifically in the small wavenumber region of Fourier space. Informed by these observations, as well as new relations found between parameters of the nonlinear spectral shape, a novel quasilinear saturation rule has been developed, able to more accurately capture the isotope scaling of turbulent heat fluxes across a range of low aspect ratio equilibria. The model is also shown to perform at least as well in other tokamak parameters, compared to contemporary models.

[1] E. A. Belli, J. Candy, and R. E. Waltz. "Reversal of turbulent gyroBohm isotope scaling due to nonadiabatic electron drive." Physics of Plasmas **26** (2019): 082305.

[2] J. Candy, E. A. Belli, and R. V. Bravenec. "A high-accuracy Eulerian gyrokinetic solver for collisional plasmas." Journal of Computational Physics **324** (2016): 73-93.