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# Nonlinearities in magnetic confinement, ionospheric physics and population explosion leading to profile resilience.

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## Abstract

In this work, we discuss nonlinearities in kinetic and fluid systems [1–12], with particular emphasis on *resonance broadening*, which plays a crucial role in nonlinear kinetic dynamics and enables fluid closures. Resonance broadening [1,3,5,6] enhances zonal flows, contributing to isotope scaling and density limits [12], the Dimits shift, and the emergence of particle and temperature pinches [9], as well as the LH transition. In cases of explosive instability, the resulting fluid equations exhibit dynamics similar to those of a population explosion [4]. These phenomena are made possible once resonance broadening causes a consistent fluid closure [5,6]. Due to the large characteristic velocities in kinetic systems, a strongly nonlinear treatment such as the inclusion of resonance broadening is essential. The effects of resonance broadening are therefore fundamental to plasma turbulence. For example, it has enabled the prediction of a particle pinch in the QualiKiz code [10], which was fitted against the nonlinear kinetic code GYRO. In our fluid closure [9], resonance broadening accounts for both temperature and particle pinches and is expected to have similar effects in TGLF (GLF23) following its calibration to GYRO simulations [11]. A novel aspect of our work is the demonstration of a mechanism that cancels linear kinetic wave particle resonances through resonance broadening [8]. Specifically, in interactions between waves with positive and negative wave energy [2–4], nonlinear frequency shifts [4] stabilize explosive instabilities by altering the sign of the wave energy. This, in turn, reverses the sign of the linear kinetic wave particle resonances, causing them to average out on the transport timescale [8].

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