A General Transport-Oriented Formulation of Orbit Loss

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February 18, 2019

Abstract

Ion-orbit-loss theories have long been invoked to explain mysterious near-separatrix observations including the L-H transition and edge intrinsic toroidal rotation. The basic idea is sound: For radial locations within about one poloidal gyroradius of the last closed flux surface (LCFS), some ions' unperturbed drift orbits will intersect the divertor plate or vessel wall, causing those ions to be lost. The outgoing gyrocenter charge density can then be invoked to explain the potential well in the far edge, and the outgoing toroidal momentum to explain a recoil-based toroidal acceleration of the plasma. However, orbit-loss models often struggle to maintain self-consistency. In particular, in steady state, the outgoing flux of ions on any given loss orbit should be restricted to the rate at which ions are supplied to that loss orbit, by turbulence, collisions, or otherwise.

In this work, a general conservative gyrokinetic framework is used to explicitly demonstrate how the steady-state orbit-loss boundary fluxes are entirely determined by upstream transport (turbulent and collisional) and upstream sources. The details of the equilibrium orbits, even accounting for large but axisymmetric and time-independent electric fields and poloidal pressure gradients, are demonstrated to contribute only by modulating upstream transport and sources. This is true not only for gyrocenter fluxes, but also for any other moments that are expressible in terms of the adiabatic invariants that determine the orbits, such as parallel toroidal angular momentum. An explicit reformulation of the orbit-loss terms facilitates their evaluation via numerical diagnostics or reduced models. For example, the transport-oriented reformulation presents self-consistent avenues to determine the orbit-loss contribution to the edge radial electric field and toroidal rotation, and thereby to address questions like the asymmetry in L-H power threshold between favorable and unfavorable ∇B configurations.