# Self-consistent orbit-flux drive for electric field and toroidal rotation

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Ion-orbit-loss theories have long been invoked to explain near-separatrix observations including the L-H transition and edge intrinsic toroidal rotation. The basic idea is sound: 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 resulting outgoing gyrocenter charge density could cause a potential well in the far edge, and the lost toroidal momentum a recoil-based toroidal acceleration. However, orbit-loss models often struggle to maintain self-consistency: the steady-state outflux of ions on any given loss orbit is in fact determined by the rate at which ions are supplied to that loss orbit, by turbulence, collisions, or sources (heating or neutrals). Further, such a balance actually applies at any closed flux surface, not just the LCFS, suggesting that orbit fluxes in a turbulent core plasma may deviate substantially from their neoclassical value, at least in some cases.

In this work, we use orbit-flux diagnostics in the gyrokinetic code XGC to explicitly calculate the self-consistent orbit fluxes, entirely determined by upstream turbulence, collisions, and sources. In axisymmetric global simulations of edge plasmas on DIII-D, ion orbit fluxes on loss orbits are found to drive the edge $E_r$ well, while the orbit fluxes on confined orbits saturate it. The quantitative significance of the loss-orbit fluxes depends on regime. In an H-mode case, the collisional ion-orbit-loss contribution to the $E_r$ well was quite small. In a comparison L-mode case, the relative orbit-loss contribution was significantly larger, although still subdominant to the pressure-gradient term. In full 5D global simulations, core turbulence was measured to drive significant radial orbit-flux advection of toroidal momentum, at levels comparable with direct momentum advection by the turbulent $\boldsymbol{E} \times \boldsymbol{B}$ drift, as well as with experimental observations.