Onset and nonlinear relaxation of coherent current-carrying filaments during ELMs and vertical displacement events in tokamaks

Understanding the onset and the nonlinear evolution of coherent current-carrying filamentary structures in the edge region of tokamaks is critically important. In particular, the localization of the heat load of these structures on the tokamak divertor could be a major determining factor of the plasma-facing component (PFC) damage tolerance in future burning plasmas. The onset and nonlinear evolution of reconnecting current-carrying filaments are examined using global nonlinear three-dimensional resistive MHD simulations with NIMROD in a spherical tokamak. To shed light onto the role of reconnection in the nonlinear dynamics, we here focus on the effect of finite edge current density. The helicity injection technique is utilized to form plasma current non-inductively. We show that physical current-sheets/layers develop near the tokamak edge under different circumstances, in particular as a peeling component of ELMs (due to bootstrap currents), and during vertical displacement events (associated with the scrape-off layer currents). In all these cases, edge current sheets can become unstable to nonaxisymmetric 3-D current-sheet instabilities and nonlinearly form edge coherent current-carrying filaments. Our nonlinear simulations are the first to identify the time-evolving edge current sheets in ST configurations. [1,2] In the case of peeling-like edge localized modes, the longstanding problem of quasiperiodic ELM cycles is explained through the relaxation of the edge current source through direct numerical calculations of reconnecting local bi-directional fluctuation-induced electromotive force (emf) terms. [2] The coherent filament structures and the nonlinear dynamics found here are very similar to the camera images of peeling modes from the Pegasus spherical tokamak. [3]

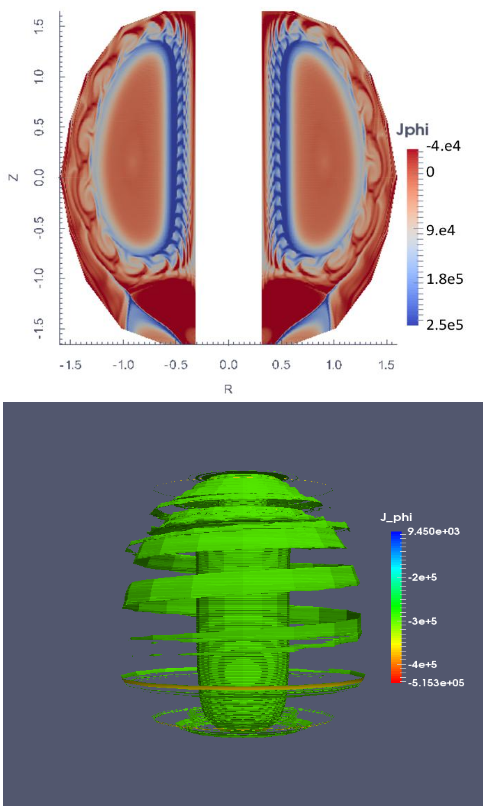

Figure 1: Top: Poloidal R-Z cut of saturated nonlinear toroidal current density. Coherent filaments form in single X point configuration, and mode structure radially extends from the closed flux region to the SOL. Bottom: Peeling-driven filament formation during plasma VDE.

Secondly, we examine the stability and formation of reconnecting edge peeling-driven filaments during vertical displacement events (VDEs). In the simulations, VDEs are induced 1) by first driving large current in the open field region to form scrape-off layer currents (halo currents), 2) by turning off the voltage to allow plasma vertical displacement downward. We show that as the plasma is vertically displaced, edge halo current-sheet becomes MHD peeling-tearing unstable and form non-axisymmetric coherent edge current filamentary structures, which would eventually bleed into the walls. We also investigate the dependency of onset of peeling-driven filaments on Lundquist number. Similar to fast reconnection due to axisymmetric plasmoids, [1] we find that the growth rate of these edge filamentary structures becomes independent of Lundquist number. Our model explains some essential asymmetric physics relevant to the experimental observations for these disruptive events. Supported by DOE grants DE-SC0010565, DE-AC02-09CH11466.

[1] F. Ebrahimi, Phys. Plasmas 23, 120705 (2016)

[2] F. Ebrahimi, Phys. Plasmas 24, 056119 (2017)

[3] M. W. Bongard, et al. Phys. Rev. Lett. 107, 035003 (2011)