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Plasmoid-mediated magnetic reconnection: From space to fusion plasmas

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Generation of coherent, current-carrying structures is prevalent in magnetically-dominated, rotating astrophysical and laboratory plasmas. Intertwining flux tubes, as well as sheet-like structures, emerging from the surface of the sun, and edge-localized filament structures in magnetically confined plasmas are examples of such current-carrying structures. In this talk, using three-dimensional simulations, I demonstrate the onset and nonlinear evolution of coherent current-carrying filaments, as well as round magnetic structures (so called plasmoids), in a global toroidal geometry. The role of magnetic reconnection, the rearrangement of the magnetic field topology, as a major underlying mechanism for the fast growth and nonlinear saturation of the localized current-carrying structures will be explained as outlined below.

As next-step spherical tori (ST) devices will operate at higher toroidal and injector flux, 3-D MHD simulations are essential for predictive capability and confirming accessibility to maximum start-up regimes in larger STs. Full nonlinear 3-D resistive-MHD simulations performed with NIMROD predicted the plasmoid instability in NSTX during plasma startup, and this was confirmed by camera images. It was shown for the first time that elongated current-sheets in *toroidal geometry* at high Lundquist number can be unstable to plasmoid instability, resulting in a transition from slow Sweet-Parker reconnection [1,2] to fast plasmoid-mediated reconnection [3]. This was the first documentation of plasmoid formation in MHD regime in laboratory (Fig. 1). Large-volume flux closure during plasmoid-mediated reconnection in the simulations of transient CHI plasma startup was obtained even in the presence of non-axisymmetric edge magnetic fluctuations. [4,5] By modeling reconnection on both single and multiple sheets, it was also demonstrated that plasmoids sometimes grow in multiple sheets in 3D, because of the large-scale magnetic field generation, when they do not in a single sheet in 2D. [6]

The importance of reconnection physics during burst-like events in tokamaks, such as ELMs or transient VDEs, has also been recently elucidated. [7] Time-evolving edge current sheets in the NSTX and NSTX-U configurations, which were identified during nonlinear 3-D MHD simulations [6], are found to become unstable and to break the axisymmetric current to form edge current-driven peeling filaments. Unlike conventional reconnection models, it was found that 1) these 3-D current-sheet instabilities evolve on the poloidal Alfvenic time scale, and 2) the growth rate of these edge filamentary structures becomes independent of Lundquist number. These structures were shown to radially extend from the closed flux region to the region of open field lines (in the SOL). It was shown that 3-D magnetic fluctuations can cause either local flux amplification to trigger axisymmetric reconnecting plasmoids formation at the reconnection site or cause the local annihilation of axisymmetric current through a fluctuation-induced, bi-directional dynamo term. The cyclic nonlinear behavior of the low-n current-driven ELMs was explained via direct numerical calculations of the fluctuation induced emf term of a current-carrying peeling filament. [7]

References

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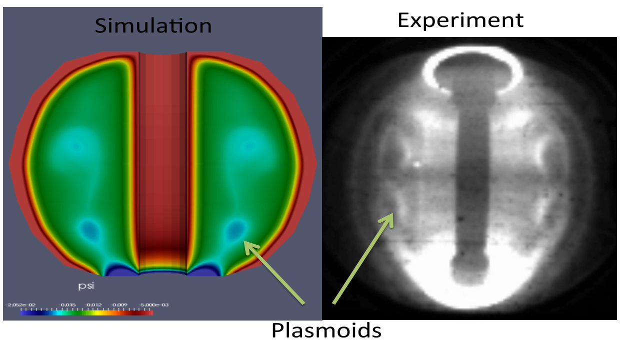

Figure1. Left: Plasmoid formation in MHD NIMROD simulation of NSTX plasma during CHI. Right: Fast-camera image of NSTX plasma shows two discrete plasmoid-like bubble structures.