Physics of plasmoid-mediated reconnection and flux closure in simulations of Coaxial Helicity Injection

Magnetic reconnection is essential for formation of closed flux surfaces and start-up plasma current in transient Coaxial Helicity Injection (CHI). Here, we explore fundamental reconnection physics, in particular reconnecting plasmoids physics, in resistive MHD simulations of transient CHI. We report two major findings: 1) formation of an elongated Sweet-Parker (S-P) current sheet and a transition to plasmoid instability has for the first time been demonstrated by simulations of CHI experiments in a large-scale toroidal fusion plasma in the absence of any pre-existing instability[1] and 2) a large-volume flux closure, and large fraction conversion of injected open flux to closed flux, in the NSTX-U geometry has also now been demonstrated for the first time[2]. Simulations have been performed using the extended MHD NIMROD code in a realistic geometry with a toroidal guide field and using experimental NSTX poloidal coil currents.

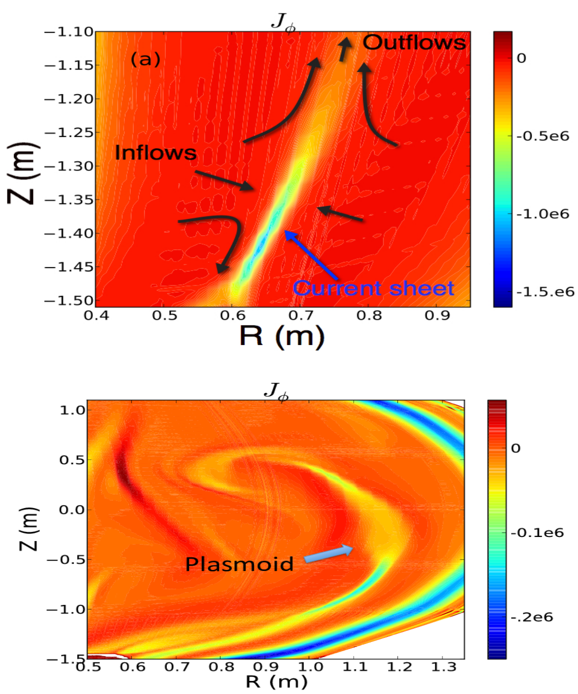

Figure 1: Top: Elongated current sheet formation during forced S-P reconnection. Bottom: Current sheet breaks up due to spontaneous reconnection at high S.

It is found that as the helicity and plasma are injected into the device, the oppositely directed field lines in the injector region are (a) forced to reconnect through a local S-P type reconnection[3,4] or (b) spontaneously reconnect when the elongated current sheet becomes MHD unstable. Consistent with the theory, fundamental characteristics of the plasmoid instability, including fast reconnection rate, have been observed in these realistic simulations. Motivated by the simulations, experimental camera images have been revisited and suggest the existence of reconnecting plasmoids in NSTX. As a result of the improved location of injector flux and shaping coils in NSTX-U, the simulations also show that the volume of flux closure is large and nearly all of the CHI-generated current is closed-flux current. It is found that the closed flux is over 70% of the initial injector flux used to initiate the discharge. Work supported by DOE-FG02-12ER55115.

[1] F. Ebrahimi, R. Raman, Physical Review Letters 114, 205003 (2015).

[2] F. Ebrahimi, R. Raman, submitted to Nuclear Fusion.

[3] F. Ebrahimi, E.B. Hooper, C.R. Sovinec, R. Raman, Phys. Plasmas 20, 090702 (2013).

[4] F. Ebrahimi, R. Raman, E. B. Hooper, C. R. Sovinec, and A. Bhattacharjee, Physics of Plasmas 21, 056109 (2014).