DPP15-2015-000935

Abstract for an Invited Paper
for the DPP15 Meeting of
the American Physical Society

Dynamics of a reconnection-driven runaway ion tail in a reversed field pinch plasma

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Non-collisional heating and energization of ions is a powerful process in reversed-field pinch (RFP) plasmas and in many astrophysical settings. Tearing activity in the RFP (including linearly and nonlinearly driven modes which span the plasma column) saturates through dynamo-like feedback on the current density profile, rapidly releasing magnetic energy and inducing a strong impulsive, parallel-to-B electric field as poloidal magnetic flux is converted to toroidal flux. The global reconnection leads to strong ion heating with a known anisotropy in temperature ($T_{\perp} > T_{||}$), suggestive of a perpendicular bulk heating mechanism. In the subset of strongest reconnection events, multiple mechanisms combine to create a most interesting ion distribution. Runaway of the reduced-friction naturally-heated ions generates an asymmetric ion tail with $E_{||} >> E_{\perp}$. The tail is reinforced by a confinement asymmetry where runaway ions approach the limit of classical cross-field transport despite magnetic stochasticity from the broad spectrum of tearing modes. Confinement is lower in other regions of the $v_{\perp}/v_{||}$ plane and reduces to Rechester-Rosenbluth-like transport experienced by thermal particles. Experiments with neutral beam injection elegantly confirm the ion runaway process and fast ion confinement characteristics in MST. Neutral particle analyzers measure an unrestricted parallel acceleration of the fast test particle distribution during the reconnection event. The energy gain is larger for higher initial ion energy (reduced drag), and deceleration is observed with reversed electric field (counter-current injection) according to runaway dynamics and confirmed with Fokker-Planck modeling. Full orbit test particle tracing in the 3D time evolving electric and magnetic fields (from visco-resistive MHD simulations) corroborates the understanding of fast ion confinement. Work supported by by US DoE and NSF.