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3D Device Simulations of a toroidal pure electron plasma with a new PIC-MCC code - PEC3PIC

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Since the pioneering experiment with trapped electron clouds performed by Malmberg in the 1970's [1], there has been extensive research conducted on different aspects of non-neutral plasmas confined in linear, cylindrical Penning-Malmberg (PM) [2, 3] traps or similar linear devices [4, 5]. The toroidal alternative for confining charged clouds, while having been experimented on at different toroidal aspect ratios [6, 7], remains comparatively less intensely modeled.
While linear magnetic traps exhibit excellent confinement and stability of the non-neutral plasma [8, 9], making them ideal candidates for experiments with exotic and expensive charged species [10], toroidal magnetic traps offer a vast and diverse array of plasma activities, studying which can have potential applications beyond the device, in other set-ups and natural plasma systems. For instance the drifts, instabilities, and transport properties of toroidal low energy plasmas can serve as a useful model [11] for the electrostatic component of the dynamics of high energy tokamak plasmas which have electrostatic and electromagnetic i.e. plasma current driven , processes happening together. Studies on the self-organization process of electron cloud profiles along the gradient, and across the curvature of the applied toroidal magnetic field can enhance understanding of self-organization of charged particles in more complex topologies, such as that observed in experimental and natural magnetospheres [12]. From the perspective of nonlinear dynamics research [13], the torodicity of the trap causes strong coupling between different poloidal modes of the electron cloud, resulting in interesting nonlinear dynamics and transport of the trapped plasma [6].
In a series of earlier works, 2D Device simulations with the 2D3v PIC-MCC code PEC2PIC had been used to investigate different aspects of non-neutral plasma dynamics in linear devices, such as the radial breathing modes and azimuthal diocotron modes in pure electron plasma [14], the nonlinear dynamics and energetics of ion-resonance instabilities in two-component non-neutral plasmas [15], and effects of ionizing and non-ionizing collisions between electrons and background neutrals on the stability and dynamics of a cylindrically confined electron cloud [16, 17].
In this work [18] a similar systematic approach has been adopted for modeling the dynamics of non-neutral plasmas in toroidal magnetic confinement. Firstly the 2D3v PIC-MCC code has been upgraded to a new 3D PIC-MCC code, **PEC3PIC** (**P**arallelized **E**lectrostatic **C**artesian **3**D **P**article-**I**n-**C**ell code). PEC3PIC is equipped with upgraded numerical features such as a Multigrid Poisson Solver replacing the SOR solver in PEC2PIC, and a generalization of the Chin's particle pusher for a non-Cartesian orientation of the magnetic field, such as the radially falling, toroidally oriented, magnetic field in a toroidal trap.
In a set of numerical experiments [18], PEC3PIC has been used for 3D collisionless simulations of electron plasma dynamics in a toroidal magnetic trap of tight aspect ratio, α=1.59, where α is the ratio of the major radius to the minor radius of the toroidal trap. It must be noted that these 3D simulations include all collisionless plasma dynamics that can take place in a toroidal configuration, such as inward shifts of the electron cloud, the combined effects of **E**X**B**, grad-**B**, and curvature drifts, diocotron modes coupling, magnetic compressions and expansions of the orbiting cloud, coupling of the cross-field dynamics with toroidal dynamics, particle transport and losses, and more phenomena.
Several new results have been obtained form these simulations [18]. For example, the plasma is observed to undergo a closed heating-cooling cycle in addition to a net heating in its diocotron motion, particle transport and losses has been numerically modeled, the confinement properties of the tight aspect ratio toroidal trap has also been tested at different Brillouin ratios of the electron cloud.

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