Discovery of a quiescent toroidal nonneutral plasma state at small aspect ratios

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Finding a quiescent quasi-steady inhomogeneous, equilibrium state of a toroidal electron plasma, with excellent confinement properties of the plasma has been a long-standing, open problem. Effective absolute or near-absolute equilibria are much sought after in every plasma trapping device. One of the most successful device configurations where near absolute thermal equilibrium condition has been achieved [1], is a straight cylindrical trap with electrons/ions, called Penning-Malmberg traps. However, toroidal magnetic fields come with natural radial inhomogeneity, due to Maxwell's equations, which has been a deterrent in achieving an absolute equilibrium. Also small fraction of ion population leads to ion resonance instability resulting in destabilization of the electron cloud.

In this presentation, existence of a quiescent quasi-steady solution is demonstrated [2] in axi-symmetric tight aspect ratio toroidal magnetic field configuration with pure electrons, using combination of a mean field theoretic extremum entropy solution [3] and high fidelity 3D3V Particle-in-Cell simulations [4]. In Figure 1, 3D density profile of quiescent quasi-steady state obtained starting from a mean field theoretic extremum entropy solution is shown. This solution satisfies Newton's laws and in that sense is accurate to all orders in $<\rho_l>/L_B$ (where $<\rho_l>$ *is* average electron Larmor radius and L_B is the magnetic field gradient length scale). Effect of ions is also addressed on the stability of the above-said quiescent quasi-steady equilibrium state [5]. A minuscule or small ion fraction introduced in the device at a particular time, is found to result in systematic destabilization of the electron cloud. With uniform electron cloud as initial solution, this study has been also extended to partial toroidal traps [6] with end plugs to investigate the electrons dynamics under similar conditions as the experimental devices. We believe that these studies will allow us to make a close comparison with experiments.

This novel quiescent quasi-steady toroidal electron plasma equilibrium exhibits peaked quasi-stationary density and potential profiles, without the center of charge motion, with excellent particle conservation. The variation of average parallel and perpendicular temperatures with major radius R is reported for the first time for a small aspect ratio toroidal electron plasma. Our finding solves a long-standing problem of obtaining a quiescent quasi-steady state of toroidal pure electron plasma, suggesting the possibility of better confinement in tight aspect ratios.

References

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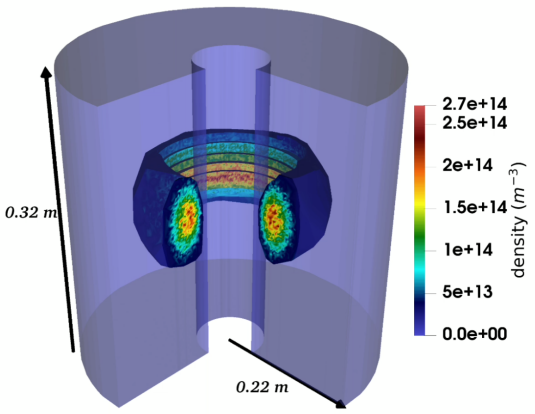

Figure 1: 3D density profile of quiescent quasi-steady state obtained from the mean field theoretic extremum entropy solution as "seed" solution in the 3D toroidal geometry (Although the device is toroidally axisymmetric, only 3/4th fraction is shown for clarity of presentation) [2].