B-I24 AAPPS-DPP2020

4th Asia-Pacific Conference on Plasma Physics, 26-31Oct, 2020, Remote e-conference

Toroidal Electron Plasma Experiment: SMARTEX-C

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Collection of like-charged particles, in spite of their mutual repulsion, can remain well-confined and be in thermodynamic equilibrium simultaneously when trapped in a cylindrical geometry using a uniform axial magnetic field and electrostatic end-plugs[1]. While this has allowed statistical thermodynamics to explain most of the collective behavior of such Non-Neutral plasmas, controlled and reproducible experiments have been possible in simple linear traps, allowing investigation of many basic plasma physics phenomena[2]. On the other hand, confining such plasmas in toroidal geometry has remained notoriously elusive[3], even though equilibrium and stability of such charged clouds are theoretically ensured with purely toroidal B field[4]. Efforts of confining electron-positron pair plasmas, investigating effects of arbitrary degree of neutrality, etc are some of the reasons that have led to renewed interest in toroidal geometries in recent times.

In the early eighties, theoretical and experimental investigations with electron plasmas in a small-aspect ratio continuous torus, initiated at Institute for Plasma Research, India, demonstrated equilibrium[5] and stability along with some interesting features, such as, inward shift of charge cloud[6], effect of external radial electric field on the equilibrium[7] etc. Confinement times, however, were limited to few 100 µs. Later, the toroidal symmetry was broken to implement P-M trap arrangement in toroidal geometry. Successful experiments in SMARTEX-C (**SM**all **A**spect **R**atio **T**oroidal **E**lectron plasma e**X**periment in '**C**' shaped geometry) led to a major improvement in confinement time to few ms[8], plagued mostly by instabilities driven by ions. In a series of upgrades and investigations that followed, the causes of instabilities were investigated and characterized leading to complete mitigation and control. Such quiescent plasmas along with upgraded diagnostics and correlation with numerical investigations[9,10] explained the drift dynamics besides demonstrating improved confinement times of a few seconds[11]. Interestingly, similar efforts reported from a large aspect ratio trap, namely LNT-II, reported excellent confinement time of few seconds with purely toroidal magnetic field[12]. Different magnetic field topologies[13] were also reported, of which RT-1[14], that traps electrons on magnetic flux surfaces by utilising a dipole B-field have demonstrated confinement times of 100 of seconds.

The biggest impediment, in improving confinement with a purely toroidal B field, has been the Magnetic Pumping Transport[15] (MPT) resulting from the inhomogeneity in B field. Proposed theoretically by O'Neil and Crook, the transport is suggested to limit the confinement time to ~2 sec (close to our results) for assumed T_e of 1 eV and major radius of ~12.2 cm. Theory also suggests such transport to be independent of B field. Further, our investigations reveal that additional factors that involves the aspect ratio of the trap and temperature anisotropy, may also affect the limit. On the other hand, parallel temperature may contaminate the estimate due to ionization and addition of electrons. A simple model by us determines the operating parameters such as pressures and injection energies that can help to avoid such a scenario. Putting together a safe operating regime, accurate temperature diagnostics, and verifying the confinement time scaling with magnetic field should lead to confirmation of the existing transport theories in SMARTEX-C and establish the limits of confinement of pure electron plasmas with a toroidal B field.

The talk will discuss this journey of SMARTEX-C and our efforts towards long time confinement of pure electron plasmas in toroidal geometries, the associated physics and the promise that it holds in exploring such plasmas as test beds for a lot many fundamental physics investigations, much like their cylindrical counterparts.

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