6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

Can a toroidal electron plasma be confined for ever – a numerical exploration!

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Straight cylindrical trap, also called a Penning-Malmberg trap, with uniform external magnetic field for radial confinement and appropriate electric field end-plugs for axial confinement, routinely confine electrons or ions. In these traps particles achieve thermal equilibrium easily in uniform homogeneous magnetic fields with excellent confinement properties under certain conditions.

In contrast, confinement of pure electron or ion plasmas in a purely toroidal magnetic field has proven to be a major challenge for the past 30 years or more. One of the issues that restricts pure electron plasma from being confined "for ever" in a toroidal magnetic field with natural curvature, is the onset of nearly-ubiquitous, toroidal diocotron oscillations and its instability driven by small fraction of ions generated from ionizing electron-neutral collisions in realistic conditions.

In this presentation, it is shown for the first time, the existence of a 3D quiescent quasi-steady state (QQS)[2, 5] of toroidal pure electron plasma, which is devoid of toroidal diocotron oscillations, using combination of a mean field theoretic extremum entropy solution (Fig. 1 (a)) and high fidelity 3D3V particle-in-cell simulations [1-4]. Superiority of the QQS solution is demonstrated by comparing the findings with a "typical initial condition" (TIC) used in laboratories today (Fig. 1 (b)). E.g. Spectrogram analysis in Fig. 2 shows higher todoidal mode numbers (with higher energy) for TIC case comparing to QQS.

In the high density limit, global particle confinement time up to 100 million times or more of the toroidal diocotron period is found with QQS state (Fig. 3), which unambiguously show that a toroidal electron plasma in tight aspect ratio geometry can be confined "for ever"[2, 5].

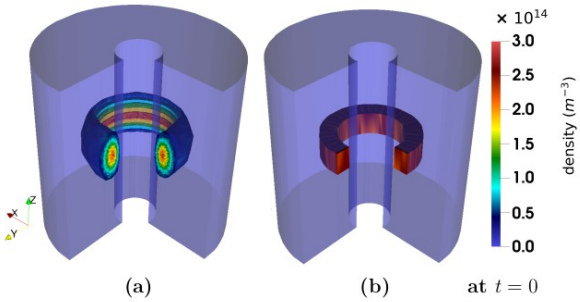

Fig 1. 3D density profile of (a) mean field theoretic extremum entropy solution and (b) TIC (although the device is toroidally axisymmetric, only 3/4th fraction is shown for clarity of presentation).

A new scaling law of confinement time with mean density and toroidal magnetic field strength has been found along with three dimensional profiles of parallel and perpendicular electron temperatures, density and plasma potential.

References

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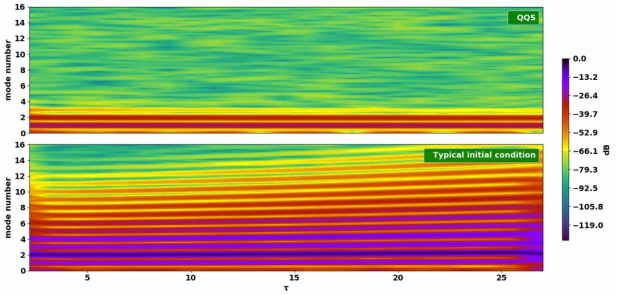

Fig 2. Comparison of spectrogram of the wall probe current for QQS solution and TIC. For TIC case higher modes (up to m = 14) are present in the dynamics with dominant m = 2 mode. For QQS a quiet spectrogram reveals very low energy in the m = 1 and m = 2 modes.

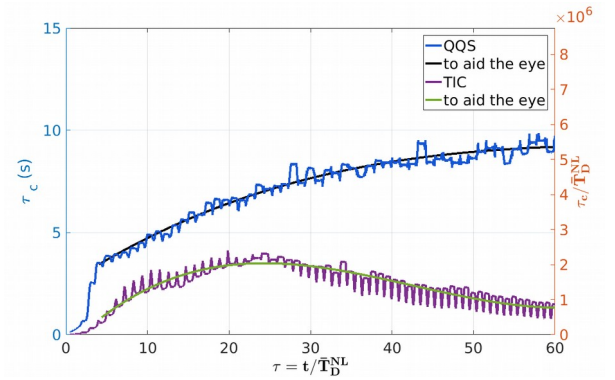

Fig 3. Comparison of global particle confinement time (τ_c) for QQS and TIC. For QQS, $\tau_c \sim 10^7$ times of the toroidal diocotron period.