Thermal equilibrium of non-neutral plasma in a magnetic dipole trap

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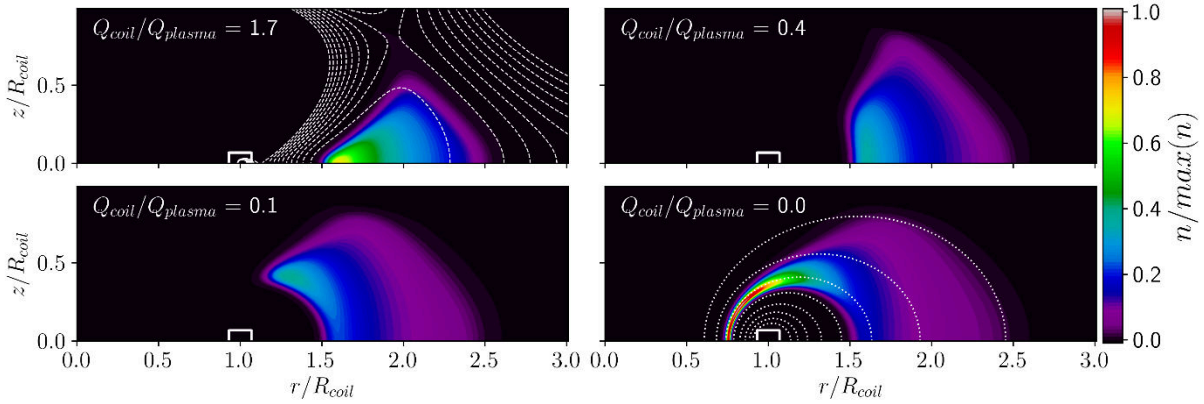
Global thermal equilibrium states for single species plasmas are routinely realized in the homogeneous magnetic field of Penning-Malmberg traps [1]. They are states of maximum entropy subject to the constancy of total energy, total canonical angular momentum and total particle number [2]. A maximum-entropy state is guaranteed to be stable and, in principle, to persist indefinitely. We generalize the theory of these states to include inhomogeneous magnetic dipole fields. The approach to global thermal equilibrium takes place in two stages with well separated time scales. On the collisional time scale local thermal equilibrium is established along each magnetic field line [3]. On the much longer transport time scale, heat conduction and viscosity bring the plasma on different flux contours into global thermal equilibrium [1]. In order to contain a global thermal equilibrium state, the effective potential as seen in the frame of reference that rotates with the non-neutral plasma needs to form a potential well. We present numerical results for local and global thermal equilibria (see figure below) including their respective zero-temperature limits [4]. We anticipate that, in contrast to a Penning-Malmberg trap, a magnetic dipole field also confines a quasi-neutral plasma, making it an attractive candidate for the creation of an electron-positron pair plasma.



Density distribution in the upper left quadrant of the r-z plane. The white rectangle represents the coil. The upper left plot shows the density distribution of a global thermal equilibrium state. The charge on the coil is chosen such, that the effective potential as seen in the frame of reference that rotates with the plasma (white dashed lines) forms a potential well. As the charge on the coil decreases the potential well is destroyed and we can only find a local, but not a global thermal equilibrium. As the charge on the coil is set to zero (lower right panel) the plasma extends along the magnetic field lines (white dotted lines).

[1] Driscoll, C. F., Malmberg, J. H. & Fine, K. S. 1988 Observation of transport to thermal equilibrium in pure electron plasmas. Phys. Rev. Lett. 60, 1290–1293.
[2] Dubin, D. H. E. & O'Neil, T. M. 1999 Trapped nonneutral plasmas, liquids, and crystals (the thermal equilibrium states). Rev. Mod. Phys. 71, 87–172.
[3] Hyatt, A., Driscoll, C. & Malmberg, J. 1987 Measurement of the anisotropic temperature relaxation rate in a pure electron plasma. Physical review letters 59, 2975.
[4] Steinbrunner, P., O'Neil, T. M., Stoneking, M. R., Dubin, D.H.E. 2023 Thermal equilibrium of collisional non-neutral plasma in a magnetic dipole trap. Under consideration for publication in J. Plasma Phys.