Hybrid FRC equilibria with fully-kinetic ions and fluid electrons

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In view of large-orbit ions in field-reversed configurations (FRC), equilibria are poorly represented by fluid or even extended-fluid models. A realistic equilibrium requires, instead, a distribution function description of the ions. Moreover, since FRCs have a closed magnetic-field core, two ion populations are needed, one for ions more-or-less restricted to the *core* region, and those in the *periphery* that can access the open end. The latter have a probability of end loss whereas the former do not. While this distinction resembles the "inside" vs "outside" the separatrix regions in a fluid description, it is notably different since both "core" and "periphery" ions can invade, if only temporarily, the domain of the other.

The steady Vlasov equation governs the equilibrium distribution. In an axisymmetric electromagnetic field structure, the general solution is an arbitrary function of the two constants of motion: the Hamiltonian, namely the energy distribution, and the canonical angular momentum, related to toroidal rotation. The combined distribution embraces both core and periphery populations. The confinement boundary separating the two populations also happens to be a function of the constants of motion. Regarding Vlasov such solutions, only a small subset of them are realistic in view of collisions, which smooth the distribution, and instabilities, which reorganize the electromagnetic field structure. Both collisions and end loss can be accommodated by requiring the Vlasov solution to be roughly consistent with the demands of the Fokker-Planck (FP) equation. The Vlasov and FP formulations are very close if the collision frequency is low compared to dynamical frequencies.

Numerical construction of such equilibria requires solving both Ampere's law for the magnetic flux function and the relatively ponderous task of a velocity-space integration at each point in space. The latter can be accommodated by the artifice of expressing the distribution function as the sum of simple "core" and "periphery" *elements* that have analytic moment integrals (e.g. density and current density). This is the case if the elements are truncated versions of the familiar rigid-rotor distribution. Moreover, summing of a small number of such elements gives the distribution function enough flexibility to access a broad range of realistic equilibria.

The foregoing procedure can be applied to plasmas with a combination of bulk ions as well as energetic beam ions resulting from neutral-beam injection. This merely adds a second ion distribution contributing to the current. The electrons, properly treatable as a fluid, also carry current, for which a simple model can be constructed. The numerical burden of computing such "hybrid" equilibrium is so modest as to take only a few seconds on an ordinary personal computer. The built-in flexibility of the distributions also allows the solver to "lock on" to routine observables in experiments. This allows rapid reconstruction of the evolving equilibrium in an experiment. Examples of such reconstructions will be presented.