Construction of chaotic and integrable equilibria for a hybrid Vlasov-Maxwell system

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The construction of self-consistent kinetic equilibrium states is important for studying stability and wave propagation in collisionless plasmas (e.g. [1]). Consequently, many studies over the past decades have been focused on calculating Vlasov-Maxwell equilibria using analytical and numerical methods. However, the problem of kinetic equilibrium of hybrid models has received less attention, and self-consistent treatments often adopt restrictive assumptions ruling out cases with irregular and chaotic behavior, although such behavior is observed in spacecraft observations of space plasmas (e.g. [2]).

In this contribution, we develop a one-dimensional, quasineutral, hybrid Vlasov-Maxwell equilibrium model with kinetic ions and massless fluid electrons and derive associated solutions. The model allows for an electrostatic potential that is expressed in terms of the vector potential components through the quasineutrality condition [3]. The equilibrium states are calculated upon solving an inhomogeneous Beltrami equation that determines the magnetic field, where the inhomogeneous term is the current density of the kinetic ions and the homogeneous term represents the electron current density.

We show that the corresponding one-dimensional system is Hamiltonian, with position playing the role of time, and its trajectories have a regular, periodic behavior for ion distribution functions that are symmetric in the two conserved particle canonical momenta. For asymmetric distribution functions, the system is nonintegrable, resulting in irregular and chaotic behavior of the fields. The electron current density can modify the magnetic field phase space structure, inducing orbit trapping and the organization of orbits into large islands of stability (cf. Fig. 1). Thus the electron contribution can be responsible for the emergence of localized electric field structures that induce ion trapping.

We also provide a paradigm for the analytical construction of hybrid equilibria using a rotating two-dimensional harmonic oscillator Hamiltonian, enabling the calculation of analytic magnetic fields and the construction of the corresponding distribution functions in terms of Hermite polynomials [4,5].

Acknowledgments
This work has received funding from the National Fusion Programme of the Hellenic Republic - General Secretariat for Research and Innovation. P.J.M. was supported by the U.S. Department of Energy Contract No. DE-FG05-80ET-53088

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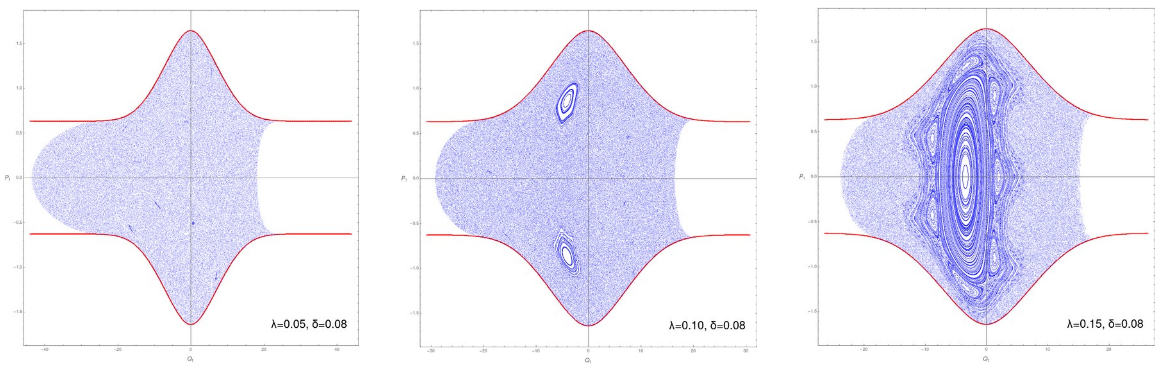

Figure 1. Poincaré surfaces of section of the nonintegrable equilibrium system resulting from non-symmetric ion distribution functions, for different values of the parameter λ. The Coriolis parameter λ, linked to the electron current density, induces orbit trapping and organization of the phase-space trajectories in large islands of stability.