Physics and open issues on magnetized plasma plumes

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This talk summarizes EP2's work on a magnetic nozzle(MN) for space propulsion. A two-fluid, steady-state model with fully-magnetized electrons but partially-magnetized ions (DIMAGNO) is used as the basis to assess the main phenomena on the divergent magnetized expansion of a plasma jet. While electrons admit simple first-integrals laws, ions behave as a supersonic fluid. The ambipolar electric field controls the conversion of the electron internal energy into ion kinetic energy and the development of a highly-supersonic plasma jet. The model explains the magnetic thrust and detachment mechanisms and the central role of azimuthal plasma currents (both diamagnetic and paramagnetic). Extensions of the base model assess the effects of plasma collisionality, electron-inertia, and induced-magnetic field in increasing jet divergence. A fully-magnetized-ion model, although more restrictive, allows to complete the physics discussed by DIMAGNO. Furthermore, that model has been extended to analyze a 3D steerable MN and show its capacity of control the thrust vector.

Moving into issues left unsolved by DIMAGNO, a first one is the correct model for electron thermodynamics of the very-rarified jet, where local thermodynamic equilibrium and the subsequent adiabatic law fail. A Vlasov-based, steady-state kinetic model of a paraxial MN has unveiled and assessed that electron collisionless cooling is due to the partial depletion of its distribution function. At present, a time-dependent version of this model is being studied in order to characterize doubly-trapped electrons and their relevance on the electron density. A second important issue, still fully open, is the final region of the jet expansion, where electrons become demagnetize: a consistent transition model from a magnetized to an unmagnetized electron formulation appears at present as very challenging.

References: M. Merino and E. Ahedo, 'Space Plasma Thrusters: Magnetic Nozzles for', in 'Encyclopedia of Plasma Technology', J. Shohet Ed., Taylor & Francis, New York, Vol. 2, 1329-1351, (2016).