Modeling plasma-magnetic field coupling: from ionosphere phenomena to laser experiments

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Résumé

The interaction between solar wind and ionosphere can generate geomagnetic storms and a depletion of the local geomagnetic field, where plasma blobs move along field lines (1). This phenomenon was also observed during the AMPTE experiments in 1984, during which barium was released to study artificial comets (2). In this presentation, we are interested in the expansion of a plasma embedded within a prescribed magnetic field. This dynamics creates areas of compressed plasma with a strong magnetic field downstream, and a magnetic depletion upstream, called a diamagnetic cavity. Recently, laboratory experiments and numerical simulations of this mechanism have been performed, with a focus on kinetic or hybrid approaches at a high computational cost (3). Here, we use a complementary formalism, ideal magnetohydrodynamics (MHD), through a code solving the Euler–Maxwell equations (4).
We start with the numerical modeling of a laser experiment conducted at LAPD (3). We obtain a similar cavity radius as in the experimental case, with a good agreement on the theoretical radii deduced from an energy balance equation. We find evidence of a coupling between the magnetic field and the plasma, with a transfer from kinetic energy to magnetic energy.

Building on these results, we develop a parametric study by varying the injected kinetic energy and a background conditions, matching two other LAPD experiments. The cavity radius increases with energy following the theoretical prediction, and decreases with higher ambient plasma densities. These conclusions are in agreement with other experiments and hybrid simulations, and give valuable insights to understand experimental measurements subject to density inhomogeneities.

This study shows that the MHD approach is relevant and efficient to estimate the maximal cavity radius for multiple sets of parameters. We further discuss current investigations of the effects of other initial parameters, as well as the impact of the coupling between ambient and debris plasma on magnetic compression intensity and speed. The wide range of parameters allowed by the fluid approach is valuable to better understand the energy transfer processes at stake, as these phenomena are relevant among a variety of regimes, encountered from the Earth's magnetotail to the solar wind-magnetosphere interactions.

REFERENCES

*Intervenant

(1) Lühr, et al., GRL, (2003).

(2) Winske, et al., Front. Astron. Space Sci., (2019).

(3) Schaeffer, et al., PoP, (2017).
(4) Cauvet, Paris Saclay University, (2022).