Thesis subject

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Modelling centrifugal instabilities in Giant planets' magnetospheres and in the Mistral Device

Rotating plasmas are very common in nature and in the laboratory devices. When density inhomogeneities are present, they are subject to centrifugal instabilities, where the centrifugal acceleration plays the role of the gravity in the classical Rayleigh-Taylor instability. The non-linear evolution of such instabilities gives rise to radial transport and the generation of coherent structures, as flux ropes and spiraling arms [1]. This dynamics can be observed in the equatorial plane of the fast rotating magnetospheres of Jupiter and Saturn, in which volcanic active moons in the inner part provide the plasma sources (and thus density inhomogeneities). Here, the creation of plasma structures is strongly linked to the three-dimensional dynamics of the magnetic field, and can generate magnetic reconnection [2] leading to particle precipitation and aurorae. Similarly, instabilities generating radial transport in accretion disks are strongly affected by the presence of a magnetic field [3].

In this context, “laboratory Astrophysics” opens the possibility of investigating these instabilities in plasma machines, as in the rotating plasma column of the Mistral device, at the PIIM laboratory [4]. In this case, different physical effects can be investigated, by modifying the plasma regimes, in a simplified two-dimensional configuration (invariant along the column axis).

This thesis will model the linear and non-linear evolution of centrifugal instability, in Jupiter and Saturn magnetospheres, as well as in the Mistral device. In particular, starting from a two-dimensional MagnetoHydroDyanamic (MHD) non-linear code, developed by the supervisor, this work will follow two different paths:
i) include the third direction, in order to investigate the complex three-dimensional dynamics that the magnetic field is supposed to follow. This dynamics possibly leads to magnetic reconnection far away from the equatorial plane where the centrifugal instability develops. For example a

similar dynamics occurs at the Earth where mid-latitude reconnection is induced by Kelvin-Helmholtz vortices [5].

ii) Include, first in the two-dimensional code, non-MHD effects (as two-fluid effects and Finite-Larmor-Radius (FLR) effects [6]), in order to understand how they influence the saturation of the instability in the different plasma regimes, leading to the formation of large- or, on the contrary, small-scale structures, with very different transport properties.

Finally, both approaches can converge, for a three-dimensional investigation of instabilities, and magnetic reconnection, including FLR and two-fluid effects. A comparison with experimental data, as well as with observational one, is planned in collaboration with the Mistral team at PIIM, and with N. André and M. Blanc at the IRAP laboratory in Toulouse, in the framework of the CANTALOUPE ANR project linked to the SOPLASMA network (gilab.com/soplasma/soplasma).

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References :

[1] N. Achilleos et al., Space Sci. Rev. **187** 229 (2015)

[2] X. Ma *et al.*, J. Geophys. Res. Space Physics **121**, 5260 (2016).

[3] S. A. Balbus *et* al., Rev. Mod. Phys. **70**, 1 (1998).

[4] S. Aggarwal *et al.*, *J. Plasma Phys.* **89** (2023).

[5] M. Faganello *et al.*, *PPCF* **64** 044014 (2022).

[6] S.S. Cerri *et al.*, Phys. Plasmas **20**, 112112 (2013).