Avis de soutenance
Astronomie et Astrophysique

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Soutiendra publiquement ses travaux de thèse intitulés

The non-resonant streaming instability: from theory to experiment

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Composition du jury proposé

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Keywords : instability, plasma, cosmic rays.

Summary. Cosmic rays can power the exponential growth of a seed magnetic field by exciting instabilities that feed on the kinetic energy of the particles collective streaming motion. Of the different streaming instabilities, the non-resonant mode, also called Bell's mode, has received growing attention as it can amplify the magnetic field well beyond its initial intensity, and generate the necessary turbulence to help confine and accelerate cosmic rays in supernovae remnants and young stellar jets shocks via the first order Fermi mechanism. In general, it can develop in a large variety of environments, ranging from the cold and dense molecular clouds to the hot and diffuse intergalactic medium. This work aims at elucidating the behaviour of the non-resonant cosmic rays streaming instability in such environments, where thermal and collisional effects

can substantially modify its growth and saturation. In the first part of this thesis, we describe the instability within fluid theory by highlighting the basic physical mechanism leading to the exponential amplification of electromagnetic perturbations, and obtain analytical predictions for the growth rate for arbitrary ion elements. Owing to its non-resonant nature, a fluid description is a sufficiently accurate model of the instability only when the background plasma temperature is negligible. To study the instability in hot environments, where finite Larmor radius effects are important, we then resort to linear kinetic theory and extend the existing analytical results to the case of demagnetized ions. We find that the unstable wavelengths are not entirely suppressed, but are instead shifted toward larger scales with a strongly reduced growth rate. The linear theory results are confirmed, and extended to the non-linear evolution in the second part of the thesis, by multi-dimensional hybrid-Particle-In-Cell simulations (kinetic ions and fluid electrons). The simulations highlight an important reduction of the level of magnetic field amplification in the hot regime [Marret et al. MNRAS 2021], indicating that it may be limited in hot astrophysical plasmas such as in superbubbles or the intergalactic medium. In colder and denser environments, such as H II regions and molecular clouds, particle collisions in the background plasma must be taken into account. We investigate numerically their impact by including Monte-Carlo Coulomb and neutral collisions in the simulations. We find that in poorly ionized plasmas, where proton-hydrogen collisions dominate, the instability is rapidly suppressed and our results from kinetic simulations confirm quantitatively existing, multi-fluid linear theory calculations. In contrast, we find that in fully ionized plasmas, Coulomb collisions unexpectedly favour the development of the instability by reducing self-generated pressure anisotropies that would otherwise oppose its growth. Numerical simulations are currently the only means to investigate the non-linear evolution of the instability and to obtain quantitative estimates of the saturated magnetic field intensity. The final part of this thesis is devoted to answer the growing need for an experimental verification of the linear theory and simulations predictions. We describe the requirements on the plasma parameters to generate the instability in an experiment, and propose two possible setups based on existing high-power laser facilities, aiming at observing and characterizing the non-resonant mode for the first time in the laboratory.