Modeling centrifugal instabilities in laboratory plasma

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This work provides a comprehensive characterization of centrifugal instabilities in fluid models of partially magnetized plasmas. The study begins with an analysis of the wave spectrum in a homogeneous, rotating fluid and is subsequently extended to non-uniform equilibria, with particular attention to the role of the fluid closure in governing the onset of instabilities. The mechanisms driving centrifugal instabilities are investigated across different models, highlighting the necessity for a unified theoretical approach. A complete pressure-tensor evolution model ([1]) is developed in cylindrical coordinates to predict the linear dispersion relation of a rotating, partially magnetized electrostatic plasma without relying on low-frequency Finite-Larmor-Radius (FLR) corrections to the gyrotropic pressure.([2],[3]). Previous models could reproduce the stability of high-azimuthal-number (high-m) modes only by including FLR corrections, whose low-frequency assumption is not valid for linear plasma devices such as MISTRAL([4], [5]), where typical instability frequencies are comparable to the ion cyclotron frequency. The present model enables the identification and characterization of both global destabilization processes and stabilization mechanisms at high azimuthal (m) and radial (n) mode numbers, providing a rigorous linear theoretical foundation. Although the study is strictly linear and therefore distant from the fully nonlinear experimental regime, it establishes a crucial theoretical basis for understanding the fundamental mechanisms underlying centrifugal instabilities. In particular, it provides a solid foundation for understanding the appearance of high-frequency, rotating, density spokes in linear plasma devices such as VKP [6] and MISTRAL [4], and for future extensions to nonlinear regimes.

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