Ion-driven instabilities in the inner heliosphere

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Linear theory is a well developed framework for characterizing instabilities in weakly collisional plasmas, such as the solar wind. In this work, we analyzed 1.5M proton and alpha particle Velocity Distribution Functions (VDFs) observed by Helios I and II to determine the statistical properties of the standard instability parameters such as the growth rate, frequency, the direction of wave propagation, and the power emitted or absorbed by each component, as well as to characterize their behavior with respect to the distance from the Sun and collisional processing. We use this comprehensive set of instability calculations to train a Machine Learning algorithm consisting of three interlaced components that: 1) predict if an interval is unstable from observed VDF parameters; 2) predict the instability properties for a given unstable VDF; and 3) classify the type of the unstable mode. We use these methods to map the properties in multi-dimensional phase space to find that the parallel-propagating, proton-core-induced Ion Cyclotron mode dominates the young solar wind, while the oblique Fast Magnetosonic mode regulates the proton beam drift in the collisionally old plasma.