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Nonlinear firehose instability and constant magnetic field strength fluctuations

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It is well known that the large scale expansion of the solar wind naturally drives plasma distribution functions towards the threshold of the oblique or parallel proton firehose instability. From a macroscopic point of view, the firehose instability arises in high-β (thermal to magnetic pressure ratio) plasmas when the pressure anisotropy ($p_\parallel > p_\perp$) is large enough to remove the restoring force due to magnetic tension, leading to an increase of magnetic energy until marginal stability is reached nonlinearly. Observations around 1 AU seem to support the idea that the firehose may play a role in controlling the anisotropy in the high-β wind. However, the solar wind is in a turbulent state, with its fastest streams in particular being permeated by large amplitude Alfvénic fluctuations: how the transition to the firehose unstable regime (in general of any instability) affects the evolution of large amplitude Alfvénic fluctuations and, vice-versa, how the presence of a background Alfvénic turbulent state affects the onset of the instability has remained largely unexplored so far.

One of the most remarkable, and yet unexplained, properties of such Alfvénic fluctuations is that the magnitude of the total magnetic field remains nearly constant, a condition that implies the existence of an intrinsic degree of coherence within the turbulent fluctuations. How such a nonlinear state can be achieved dynamically in the different plasma β regimes remains to be understood.

Here we investigate the nonlinear evolution of large amplitude Alfvénic fluctuations in the firehose unstable regime by revisiting its traditional theory and by examining the nonlinear saturation mechanism. We demonstrate that at saturation the system evolves towards nonlinear states that correspond to broadband magnetic field fluctuations with an overall constant magnitude of the magnetic field. These nonlinear states provide a basin of attraction for the long-term nonlinear evolution of the instability, a self-organization process that may play a role in maintaining the constant-B Alfvénic states seen in the solar wind in the high-β regime.