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Long-term Alfvén instability nonlinear simulations and high-bandwidth linear eigenmode surveys

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Fast ion driven Alfvén instabilities are often observed to persist at sustained/steady amplitudes in experiments for 105 to 106 Alfvén times (τ_{Alfvn} = $R_0/\vee_A$). Nonlinear saturation effects and mechanisms that lead to self-organized states are important since they influence the mode intermittency and associated fast ion transport levels. Gyro-Landau fluid models (TAEFL/FAR3D) have achieved very long simulation times for these instabilities (up to 50,000 Alfvén times). This model uses predictor-corrector time stepping to achieve numerical stability and projects the 5D phase space of the fast ion kinetic problem down to 3D to attain good efficiency and turn-around times. The sustained nonlinear state requires a balance between transport of the fast ion component into the resonance regions and transport out by nonlinear flattening of the distribution function; also, zonal flows (with neoclassical damping) and currents aid in regulating the amplitudes. The following figures show two examples of the simulated time variation of the fluctuating poloidal magnetic field at the plasma edge from an RSAE instability. In (a,b) no external source of fast ions is imposed, and the nonlinear density profile flattening, zonal flows and currents achieve a balance which allows sustained fluctuations. In (c,d) a fast ion density source is used that freezes the fast ion profile at its initial state; this leads to bursting in the nonlinear amplitudes with limit cycles. In the linear regime, gyrofluid models can also be solved as eigenvalue problems, facilitating mode surveys over wide frequency ranges and parameter variations. Applications to low frequency (BAE/BAAE) instabilities have been made; such techniques are also useful in understanding nonlinear dynamics and mode couplings.

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Figure 1 - Nonlinear Alfvén mode evolution of $\delta B_\theta/B_0$ (a,c) and spectrograms (b,d) for a steady saturated state (a,b), and a pulsating saturated state (c,d).

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