Analytic characterisation of ideal inertial type instabilities in tokamaks with large edge pressure gradients

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INTRODUCTION

- Tokamak H-mode: High performance accompanied by ELMy (sudden and violent) [1] High energy/particle loads \( \Rightarrow \) Material deterioration/Plasma contamination
- OH-mode: High performance (large edge pressure gradients and high \( r_e \)) with low heat loads. ELMs replaced by low-\( n \) coherent edge MHD activity (Edge Harmonic Oscillations). EHOs always present in OH-mode discharges [2][3]
- EHO physics: Numerical simulations (stability and 3D equilibrium) show unstable equilibrium states with internal-like characteristics localised near the edge (no core activity) [4][5]
- GOAL: Analysis of edge stability with analytic tools focusing on Edge Inertial Modes (EIM)

EXPERIMENTAL EVIDENCE

- Peeling-Ballooning (P-B) theory for large-\( n \) [6] can not catch some EHO features which are:
  - Below P-B stab. bound.
  - Rotation freq. \( \propto n \)\(^{3/2} \) pol.
  - Radial width \( \propto n \)\(^{3/2} \) pol.

- Internal modes: \( m = m \pm 1 \) Coupling (due to Jacobian \( \theta \) oscillation) low-\( n \) (fixed) Fourier modes with nearly resonant flat \( q \) large pressure gradient [7]. Purely toroidal mechanism (common in the core)

Does it work at the edge?

PHYSICAL MODEL

- Ideal MHD, large aspect ratio approximation, shifted circular toroidal surfaces framework
- Equilibrium modelling identifies three regions. Various choices (step-like or tanh) for equilibrium \( q \) and \( \rho \)

STABILITY ANALYSIS

- Low-shear/shared/vacuum treated separately
- Mass density gradients required for explaining \( \rho \)
- Subsonic toroidal rotation (step-like model, simpler)

- Sheared/Vacuum regions \( Q = k^2/\omega^2 + A_1 \) with \( A_1 = \text{ modified } (1 + 2 \rho^2, \nu_2 = a + n^2, a \propto \rho^2) \):
  \[ L_{ \text{av} } = 0 \]
  \[ L_{ \text{av} } = \frac{1}{2} \frac{2 A_2}{(1 + 2 \rho^2)^2} \]
  No coupling/inertia: \( a \to 0, A_1 \to 0 \)

- Low shear region internal coupled equations:
  \[ L_{ \text{av} } \sum_{n} \frac{r_{\text{in}}}{2 \pi m} \frac{r_{\text{in}}}{2 \pi m} \frac{r_{\text{in}}}{2 \pi m} \frac{r_{\text{in}}}{2 \pi m} \frac{r_{\text{in}}}{2 \pi m} \frac{r_{\text{in}}}{2 \pi m} \frac{r_{\text{in}}}{2 \pi m} \frac{r_{\text{in}}}{2 \pi m} \frac{r_{\text{in}}}{2 \pi m} \frac{r_{\text{in}}}{2 \pi m} \]
  \[ - \frac{1}{2} \frac{2 A_2}{(1 + 2 \rho^2)^2} \]
  No coupling/inertia: \( a \to 0, A_1 \to 0 \)

- Sheared/Vacuum regions: \( \mu = n/m, q \) monotonic
  \[ \mu \text{ (or) } \frac{\mu}{\mu_\text{step}} \]
  \[ \mu = \mu_\text{step} \]

- Low shear region: \( \mu = \mu_\text{step} \)

- Three harmonic equations combine in a single one

- Integral-type dispersion relation [8][9]

- Ideal wall: Simplified stability criterion (step model low-shear/-shared)

- Conclusions

References:


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