Testing a New Theory for Small Plasma Eruptions in Tokamaks Using Gyrofluid Simulations

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Introduction

- Turbulent transport across magnetic field lines degrades confinement in MCF (through heat and particle loss).
- Micro-instabilities drive this turbulence, i.e. instabilities with a wavelength, perpendicular to the magnetic field line, on the order of the ion Larmor radius.
- Conventional MHD picture of a ballooning mode is one that constructively interferes on the outboard "bad curvature" side, and destructively interferes on the inboard side.

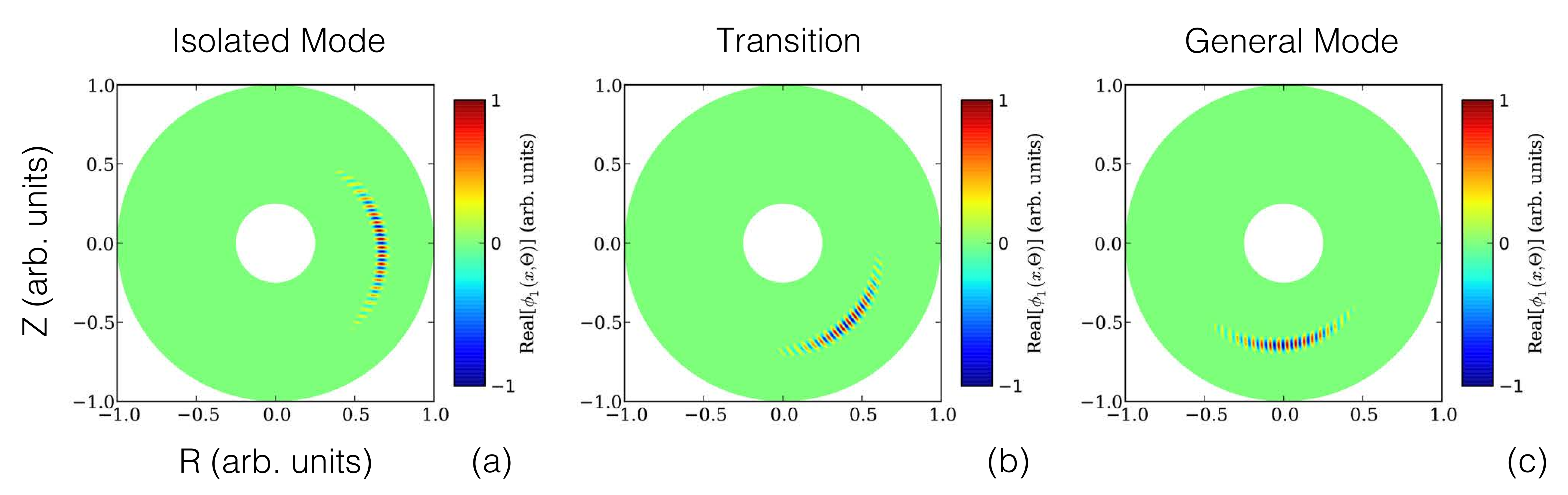

Figure 1: Evolution of the radial profile of an instability mode, from the IM (a) through to the GM (c) [1].

Motivation

- Previous work [1, 2], showed that the MHD picture is the maximally unstable mode, referred to as the **Isolated Mode (IM)**, and a more stable mode balloons towards the top or the bottom of a tokamak, called the **General Mode (GM)**.
- Reaching a critical value of flow shear in the plasma can cause a sudden transition between the GM and the IM, which could provide a model for small plasma eruptions, a.k.a. small edge-localised modes (ELMs).
- This theory has been demonstrated using a "ballooning formalism" that reduces the problem to 1D [3], and also in 2D by using a simple fluid model [1].
- Core deliverable of this project is to demonstrate the same physics as in [1-3], but with a more realistic gyrofluid model...

BOUT++

- Object-oriented C++ code written to simulate 3D fluid equations in curvilinear coordinates.
- Designed for efficiently simulating tokamak edge plasmas.
  - Recent release is able to simulate non-axi-symmetric geometries such as stellarators [4].
- Has been proven to show good agreement, in terms of mode structure and growth rate, with more "traditional" linear MHD eigenvalue codes such as ELITE (see fig. 2) [4].
- Many cumbersome HPC tasks are handled behind the scenes, e.g:
  - Parallel communication
  - Differential geometry
  - File input/ output
  - Memory management

Gyrofluid Model

- We will be using a gyrofluid model based on the one developed by Ma et al. [5].
  - However, model will be taken to the electrostatic limit.
- Gyro-averaging reduces the computational complexity of the model by removing a dimension.
  - Charged particle Larmor orbits are gyro-averaged as planar discs, which reduces a 6-dimensional problem to a 5-dimensional one (see fig. 3).
- Technically Ma et al., use a gyro-landau-fluid (GLF) 3 + 1 model which contains finite Larmor radius effects, as well as Landau damping, and toroidal resonance effects.

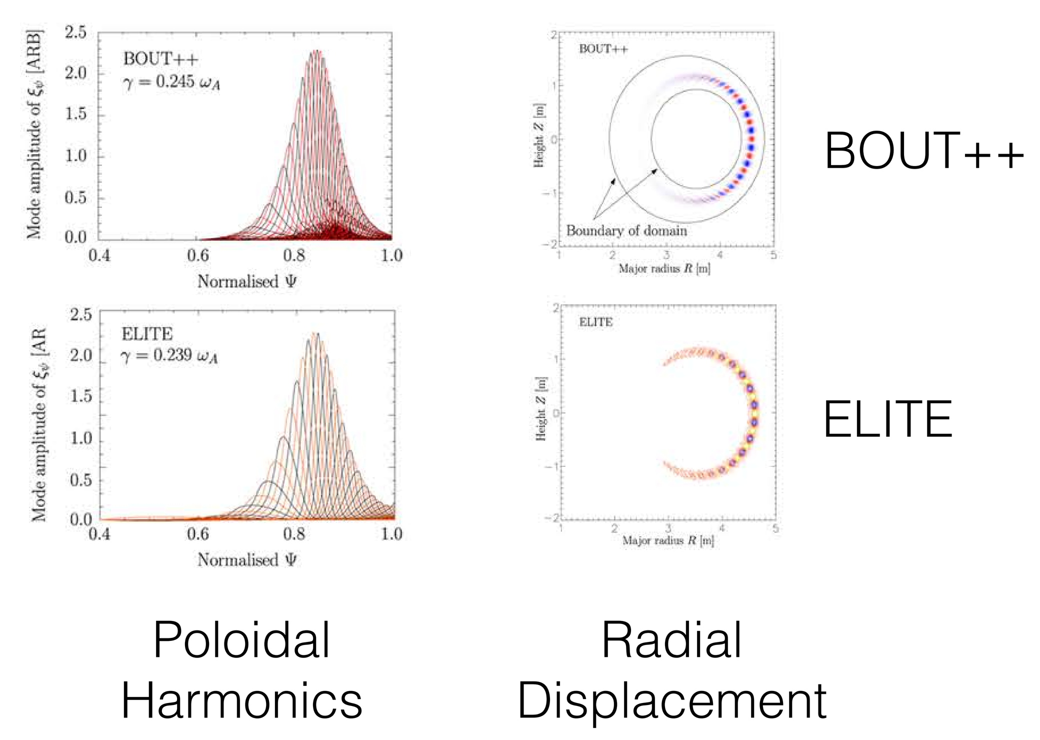

Figure 2: BOUT++ agreement with ELITE [4].

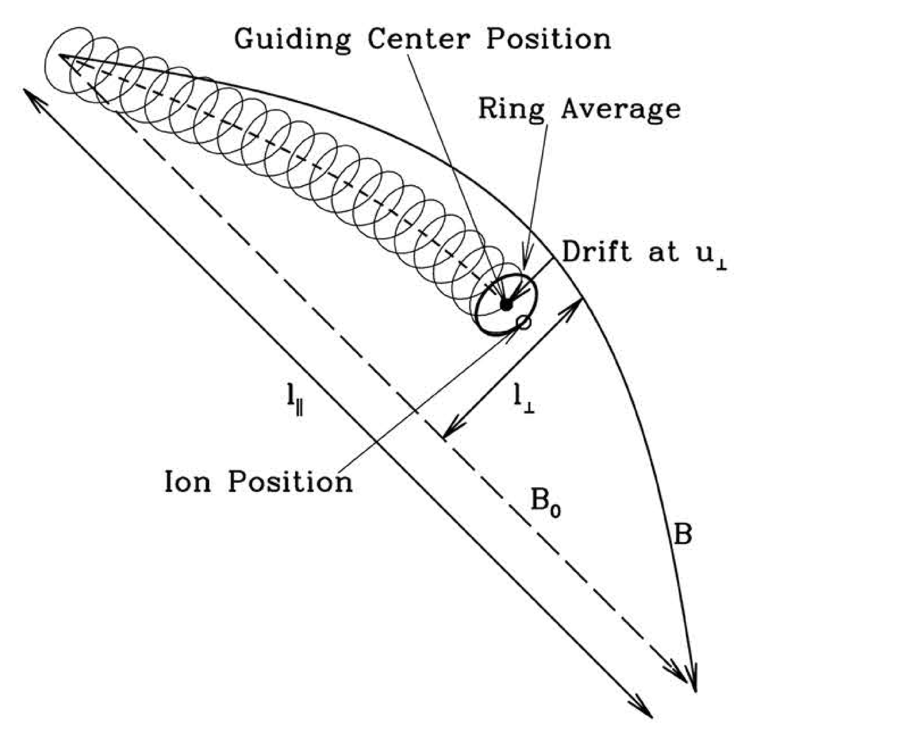

Figure 3: The gyrokinetic approximation [6].

Project Plan

- Implement the physics parameters from [1], using the gyrofluid model from [5] (and using BOUT++).
- Obtain the GM, IM, and a transition between them.
- Investigate the growth rate of the instability as a function of time.
- Investigate if there is a set of trigger parameters.
- Add more physics, e.g. nonlinear effects.

Theory | Code & Model Assumptions | General Information

References

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