Australian National University

Simons-Funded Institution

Team Australia

RL Dewar Principal Investigator

THE UNIVERSITY OF SYDNEY

Usyd Math & Stat: Nathan Duignan, Lindon Roberts

THE AUSTRALIAN NATIONAL UNIVERSITY

ANU-MSI: Bob Dewar
Matthew Hole
Kenneth Duru
(Arunav Kumar, has left for MIT)
Arash Tavassoli, welcome!
*Dean Muir**
*Sandra Jeyakumar**
*Nick Bohlsen**
*Tom (Rongping) Tang**
*Justin Hew**

ANU-RSPhys: Vanessa Robins

UWA Math & Stat:
David Pfefferlé, *David Perrella**

*denotes *students*

International Collaborators

Singapore - NTU: Zhisong Qu
USA – PPPL: Stuart Hudson, Yi-Min Huang
USA – UWisc: Adelle Wright
Japan - Naoki Sato: NIFS

Hole: Alfvén eigenmodes in stellarators including continuum damping and interaction with energetic particles.

Jeyakumar*: Structure-preserving numerical methods to add collisions to Vlasov-Maxwell systems, immediately extendable to general geometries and useful for accurate long-time simulations (M. Kraus IPP Garching collaborator)

Pfefferlé, Duignan, Perrella*: 3D magnetostatics: existence of solutions and necessary properties, flux coordinates and winding numbers, pathological cases, Beltrami fields

Duru, Hudson, Muir*, Tang*: SPEC development – New Discontinuous Galerkin Spectral Element Method to MRxMHD

Stellarator Emeriti present

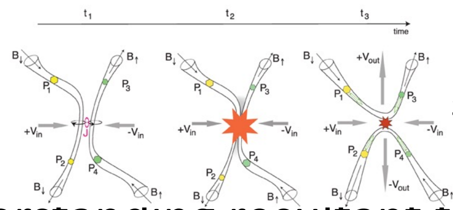
- Myself: Worked on data acquisition on Model C, and heliac stability in “straight” approximation at PPPL for heliac proposal; working on extending relaxation theory
- Henry Gardner: thesis on free-boundary equilibrium of heliac in “straight” approximation; and bootstrap currents in stellarators at Garching
- Boyd Blackwell: Chief experimentalist on ANU’s H-1 and co-proponent of our successful National Facility grant
- Alan Glasser: First author on Glasser-Greene-Johnson resistive paper (Arunav has shown SPEC can do resistive stability); and has developed 3-D DCON code for stellarator applications

Inconsistency in variational MRxMHD – beyond KAM

- The stepped-pressure equilibrium code *SPEC* is conceptually based on MRxMHD, *Multiregion Relaxed MHD*:
  - Assumes Taylor relaxation: minimization of total energy while conserving ideal-MHD (IMHD) invariant *magnetic helicity* over multiple *relaxation regions*, in which other microscopic IMHD magnetic constraints are broken, allowing *reconnection*
  - Gives linear Beltrami equations as Euler-Lagrange equations
  - Assumes KAM theory applies at robust toroidal *interfaces* separating these relaxation regions, with sufficiently *irrational* rotational transforms where lack of proximity to resonant rationals suppresses reconnection
- Problems:
  - This KAM assumption is based on 1½ D Hamiltonian dynamics, but ideal MHD (IMHD) is an *infinite-dimensional* Hamiltonian system.
  - The shapes of the interfaces *change* as the SPEC plasma relaxes toward minimum energy. But, under shape change, conserving magnetic helicity à la Taylor, the interface rotational transforms are *not* conserved so *relaxation across interfaces may occur*
- Thus, we seek a *regularization* of IMHD where sufficient reconnection is allowed in arbitrarily small regions so that the plasma can self-organize to a SPEC-like equilibrium (a finite number if toroidal reconnection barriers) if this the minimum energy state, **or to some other state?**

Grand Challenge: Self-consistent nonlinear slow dynamics of 3D MHD plasmas supporting fractal pressure gradients

- Aim: To formulate a truly variational 3-D MHD equilibrium code that has a sounder mathematical basis than SPEC in that it allows magnetic surfaces of arbitrary topologies to be created and destroyed during optimization toward a minimum-energy state
- Topology changes require *weak* ideal MHD: just enough relaxation of conventional ideal MHD to allow reconnection in the *small volumes* where reconnection occurs:



Interchange of flux rope segments via reconnection: red indicates reconnection region

- Toward anticipating and understanding resultant fractal pressure profiles:
  - Use SPEC to approximate a devil's staircase with many KAM interfaces with irrational transforms chosen by Farey tree construction (**Hudson**), maybe using a pruning algorithm (**Qu**)
  - Solve anisotropic heat diffusion equation in chaotic magnetic fields (Hudson). New Julia code (**Muir***) for efficiently and accurately computing the solution using the summation by parts formulation, which gives a provably stable discretization
  - Use topological data analysis (**Robins, Bohlsen***) to characterize fractal magnetic fields and pressure profiles across many scales
- Compare IMHD regularization approaches that allow reconnection
  - Constantine & Pasqualotto's Voigt regularization https://arxiv.org/abs/2208.11109
  - Discretization methods, e.g. discrete Galerkin, …
  - Physics-based regularization, e.g. low-resistivity MHD, Ideal Ohm's Law via Lagrange multiplier (next slides)