ANU-ITER PROJECTS

Synthetic Diagnostics for Prediction, Control and Integrated modelling in ITER

(Matthew Hole, MSI)

https://maths.anu.edu.au/people/academics/matthew-hole

Fusion plasmas can support a wide range of electromagnetic waves, ranging from pressure and current gradient driven modes to those driven unstable by fast particle-wave resonance. In a tokamak such magnetohydrodynamic (MHD) modes vary in impact on the plasma, and range from performance limitation (edge localised modes) through to disruption (edge current driven kink). The diagnosis and control of fusion plasmas is contingent on the accurate modelling, prediction, and reliable measurement of such modes.

The ITER tokamak is the world's largest science project. When constructed in 2025 it will be the world's largest and highest performance tokamak, designed to demonstrate the scientific feasibility of fusion power. An opportunity exists to work with scientists in the ITER Organisation to develop an integrated modelling solution for the statistical inference of MHD/EP driven mode activity, initially focusing on magnetic probes data. The components include:

a) Synthetic data generation: use of MHD/energetic particle codes to generate synthetic diagnostic data convolved with noise.
b) MHD analysis: develop and install analysis tools to extract mode numbers, wave vector, polarization and compute mode statistics.
c) Statistical inference: develop a Bayesian inference implementation of (b).

The plasma Theory and Modelling Group has extensive expertise in the computation of equilibrium and stability in toroidal confinement (both tokamaks and stellarators). Prof. Hole, an ITER Science Fellow, is an international expert in MHD analysis of fusion plasmas, spanning probe design and construction, through to advanced signal processing and MHD analysis. The project would also extend existing expertise in Bayesian inference of tokamak equilibria to mode analysis. The project also has scope to expand to other diagnostics.

In general, the integrated modelling of complex systems with a large collection of heterogeneous diagnostics with physics/process models is an outstanding modelling challenge portable to other fields, such as climate science.

Equilibrium and stability of ITER configurations with resonant magnetic perturbation. (Zhisong Qu, MSI)

https://maths.anu.edu.au/people/academics/zhisong-qu

The existence of good magnetic flux surfaces is only guaranteed in idealised toroidally axisymmetric configurations. With the loss of symmetry, the field lines tangle around a fixed point, creating so called magnetic islands, or when multiple islands overlap, regions of fine line chaos. In ITER, broken toroidal symmetry is introduced deliberately, through the use of resonant magnetic perturbation (RMP) coils, to supress large explosive instabilities known as edge localised modes (ELMs). It is therefore crucial to evaluate the equilibrium and stability of magnetic field configurations with RMP for ITER scenarios.

This project makes use of the Multi-region Relaxed Magnetohydrodynamics (MRxMHD) model and the Stepped Pressure Equilibrium Code (SPEC), co-developed by ANU and Princeton Plasma Physics Laboratory. The baseline axisymmetric magnetic field of ITER will be accessed in the ITER database. The RMP field will be added to the boundary condition of a free-boundary SPEC calculation to obtain a sequence of equilibria with increasing 3D perturbation field and thus size of the islands and chaotic fields. The stability of the system will then be computed from three different ways: The Hessian matrix from SPEC, a dedicated ideal MHD stability code, and a time evolution code such as M3D-C1. A parameter scan will be conducted to understand the effect of 3D perturbation field on plasma waves and stability.

Fusion versus Alternative Means of Supplying Zero-Carbon Energy in Seasonal Climates. (David Stern, Crawford)

https://crawford.anu.edu.au/people/academic/david-stern

In a seasonal climate such as south-eastern Australia or Europe, Japan, USA etc, there are four main ways of meeting the demand for energy in a zero-carbon emissions regime:

- Seasonal scale storage of energy
- Energy transport from other regions
- Baseload zero-carbon energy – nuclear fission or fusion or very large-scale hydroelectricity such as in Brazil
- Excess capacity of intermittent energy – e.g. over-investment in solar power to provide sufficient energy in the winter

How large a role is each of these likely to play in a future world? How will this vary regionally around the world? What role could fusion play, taking into account the likely future costs and other characteristics of each technology?

Projecting Future Costs of Energy Supply Technologies (David Stern, Crawford)

https://crawford.anu.edu.au/people/academic/david-stern

Most energy supply technologies are initially costly but their costs decline over time. Nuclear fission though seems to be an exception to this rule. What can we learn from the history of various energy technologies? Is there a common model that can explain the rate of decline in cost of the various technologies? How could we know ahead of time, which technologies are likely to be more successful? What does this imply for the future costs of fusion power?

Automated controller synthesis for studying plasmas under toroidal confinement (Charles Gretton, CS)

https://cecs.anu.edu.au/people/charles-gretton

This project involves deep learning for modelling plasmas in toroidal confinement for the purposes of synthesizing useful controllers. We will automate workflows in controller synthesis, by leveraging advances in SMT---i.e. SAT(isfiability) Modulo Theories systems, and/or novel approaches to modelling and optimising hybrid dynamical systems using tiered connectionist architectures. We will leverage data from a range of experiments, including the UK Mega Ampere Spherical Tokamak, the European Joint European Torus, and the South Korean KSTAR tokamak.

Algorithms for data assimilation of systems of differential equations: towards real time control (Lindon Roberts, MSI)

https://maths.anu.edu.au/people/academics/lindon-roberts

Physical processes modelled by systems of differential equations appear in a variety of settings, such as edge localised mode instabilities in tokamaks. Data assimilation is a process of synthesising (possibly accurate) models with (noisy) observations for parameter and state estimation.

This project would develop novel multi-fidelity optimisation algorithms and apply them to data assimilation problems from the study of confined plasmas. The goal would be to develop an efficient system for parameter and state estimation of complex systems, which could provide a starting-point for the development of real-time control systems.

This project is motivated by the work of Arter et al (IEEE International Symposium on Circuits and Systems, 2018).

Gyrokinetic simulations of the long-time scale interaction of Alfvén eigenmodes with plasma instabilities and turbulent transport (M. Hegland)

https://researchers.anu.edu.au/researchers/hegland-tm

The full transport of particles in toroidally magnetic confinement plasmas is a function of the sources sinks, collisions and all the modes of the system. The leading frontier of burning plasma physics is the study the synergistic impact of Alfvén Eigenmodes with microturbulence [E. M. Bass, R. E. Waltz, Phys. Plas. 24, 122302, (2017)] Gyrokinetic codes such as GENE [http://genecode.org/] are computationally expensive, are used extensively for microturbulence and transport studies and able to solve nonlinear gyrokinetic equations on a fixed grid in five-dimensional phase space (plus time). Very recently, [Di Siena et al, Phys. Plas. 25, 042304, (2018)] extended GENE to support arbitrary background distribution functions which might be analytical, or obtained from numerical fast ion models. These studies showed turbulence stabilisation due to fast ions is substantial, and this improves the quantitative source / sink power balance agreement with experiments.

Prof. Hegland is an expert in utilisation of the GENE code for gyrokinetic turbulence calculations, and has implemented sparse-grid combination techniques to GENE to solve the gyrokinetic eigenvalue problem. Using the recent extension of GENE to model more realistic distributions, the student would compute growth rates and nonlinear simulations for Alfven eigenmodes with the thermal ion and electron driving gradients retained in the gyrokinetic equations, on local flux surfaces. The purpose is to determine the confined fast ion stiffness (confinement) as a consequence of Alfven eigenmode activity and turbulence transport, and build beyond the recent critical gradient calculations.

A multifidelity approach to multi-mode simulations in burning plasmas (Stephen Roberts)

https://maths.anu.edu.au/people/academics/stephen-roberts

Multifidelity modelling is a computation technique that offers acceleration and/or tractability of numerically challenging problems such as the study of multi-mode simulations in burning plasmas. Typically, the nonlinear physics models used to study burning plasmas span a range of fidelities. From high to low fidelity they are full particle in cell simulations (MEGA), gryokinetic simulation (GENE), a drift-kinetic simulation (HAGIS, HALO), and reduced quaslinear models that model systems up to the onset of saturation. In this project, a multifidelity modelling approach will be developed for the multi-mode simulations in burning plasmas. Our approach will be guided by the multifidelity approach used in computational fluid dynamics for analysing turbulent flow. From high to low fidelity, these include direct numerical simulations (DNS), large eddy simulations (LES), and Reynolds averaged Navier-Stokes (RANS). All of these model turbulent flows, but DNS resolves the whole spatial and time domain to the scale of the turbulence, LES eliminates small-scale behaviour, and RANS applies the Reynolds decomposition to average over time. Taking advantage of relationships within the hierarchy of models, we will develop a multifidelity surrogate model capable of efficiently scanning high dimensional multi-mode parameter spaces. This will involve combining ideas from high dimensional multifidelity interpolation with parameter dimensional reduction methods such as active subspace together with the efficient encoding of the output using reduced basis methods.

Novel Symmetry tools to exactly linearize nonlinear control systems (Peter Vassiliou, MSI)

https://researchers.anu.edu.au/researchers/vassiliou-pj

This project would explore and develop applications to plasma physics using ideas from geometric control theory and Hamiltonian dynamics staring with a single charged particle. The ultimate goal would be to try to build controllers using time-varying magnetic fields to help guide a plasma.

Nonlinear analysis of fixed points of the Hasegawa-Wakatani equations (Linda Stals)
https://maths.anu.edu.au/people/academics/linda-stals

The Hasegawa-Wakatani equations describe drift wave turbulence for warm 2D plasma, and have been successful in describing a Kolmogorov wave number spectrum in the edge of fusion plasmas [Phys. Rev. Lett., 50 (1983), pp. 682– 686.]. This system of equations may also be used to predict and study the behaviour of plasma flow, and admit solutions with chaotic behaviour. Stability analysis of the flow requires results over prolonged time series, which places a strain on computational resources. Results can only be achieved for a wide choice of parameters by using numerical methods that allow long time steps and do not pollute the results with numerical instabilities. [SIAM J. SCI. COMPUT. Vol. 31, No. 2, pp. 961–986, 2008].

In this project a third order non-linear analysis around stationary points will be performed to validate numerical behaviour around bifurcation points. A wider outcome would be the development of a validation procedure for time evolution codes. The validation and verification of fusion plasma simulations is important in establishing the capability to simulate / predict ITER scenarios.

First Wall Loading (Wojciech Lipinski, RSEEME)

https://cecs.anu.edu.au/people/wojciech-lipinski

The wall of fusion reactors is subject to extreme thermal and ionising radiation loads. The wall temperature is required to remain wall to facilitate magnetic functions of the wall for plasma confinement. In this project, a numerical model will be developed and applied to study thermal and ionising radiative load on the first wall to predict wall operational conditions and inform wall material design.