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ANU-ITER PROJECTS

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?

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Computational Scalability and Robustness (Peter Strazdins, CS)

https://cecs.anu.edu.au/people/peter-strazdins

This workstream seeks apply techniques to improve the parallel scaling, computational speed per given accuracy, of MHD workloads, including the nonlinear and massively parallelised codes MEGA and JOREK. Techniques to be studied include time parallelism, sparse grid and GPU acceleration.

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.

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.

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).

Visualisation of plasma in a fusion reactor using augmented reality (Henry Gardner, RSCS)

https://cecs.anu.edu.au/people/henry-gardner

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.

High temperature ceramics (Takuya Tsuzuki, RSEMEE)

https://cecs.anu.edu.au/people/takuya-tsuzuki

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.

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.