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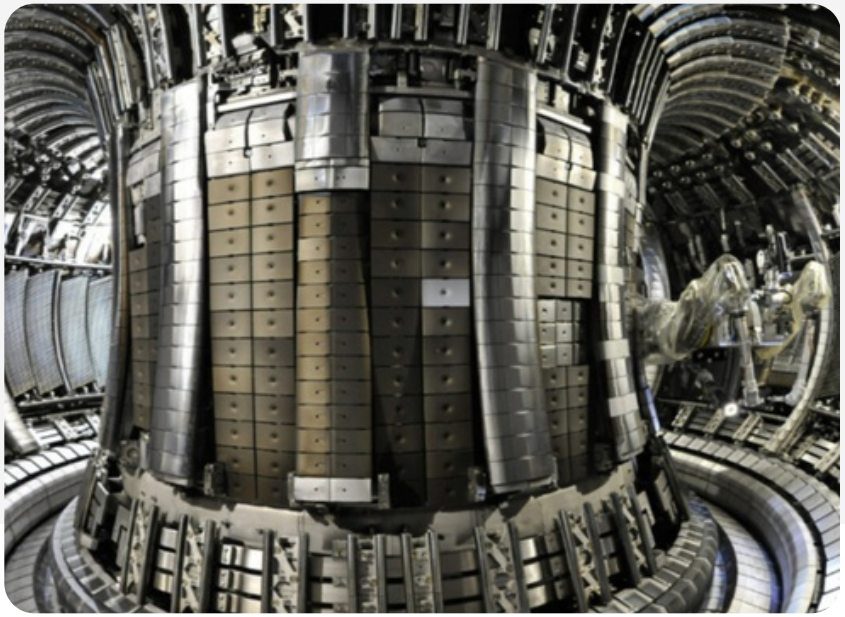

Case Study: Deploying fast machine-learnt models for fusion plasmas

How UKAEA optimised turbulence simulations using digiLab's uncertainty-aware machine learning.

Impact at a glance

~100,000 x

Faster than direct simulation, with reliable accuracy

4 x

more efficient sampling

100,000's

of CPU hours saved

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About UKAEA

digiLab is working in partnership with the UK Atomic Energy Authority (UKAEA) on the STEP programme, which aims to build a prototype fusion energy power plant by 2040. As part of this, digiLab is supporting multiple projects that address some of the toughest scientific challenges in plasma physics.

Image: Output predictions (growth rates) from digiLab's emulator of plasma turbulence.

> Delivering the fusion roadmap will require a big investment in digital technologies. And at the heart of those technologies are the solutions digiLab is working on.
>
> **Dr Rob Akers, Director of Computing Programmes & Senior Fellow, UKAEA**

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The Challenge

Fusion machines require plasma to be **confined** and **controlled** at extreme temperatures. A major barrier to this is **turbulence** - the chaotic and irregular motion of particles that causes energy leakage from the tokamak. **Predicting turbulence accurately is critical** to reactor design, but traditional simulations are computationally prohibitive, requiring millions of CPU hours and producing incomplete insights.

The Solution

digiLab developed state-of-the-art machine learning emulators for **Micro-Tearing Modes** (MTMs) and **Kinetic Ballooning Modes** (KBMs), applying both classification and regression algorithms. These emulators incorporate **Uncertainty Quantification (UQ)**, providing engineers with trustworthy **confidence intervals** around predictions. This allows researchers to understand reactor performance under varied conditions, prioritise physical testing through Active Learning, and design more effective control strategies.

The Approach

digiLab and UKAEA partnered to develop fast emulators that accelerate turbulence simulations. This collaboration - now in its third year - applies **UQ** methods to ensure reliable predictions, even when training data is sparse. By focusing on turbulent modes specific to **spherical tokamaks,** the project addresses areas of plasma behaviour that remain critically understudied.

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The results

Provided results at up to

~100,000 x

the speed of direct simulation, with reliable accuracy

opening doors to otherwise impossible investigations.

4 x

reduction in redundant simulations

thanks to active learning and more efficient model sampling.

Provided

100,000's

savings

in CPU hours, for better performance, reduced energy consumption and costs.

As UKAEA's strategic partner for Uncertainty Quantification, digiLab is helping tackle one of engineering's greatest challenges; making commercial fusion energy a reality.