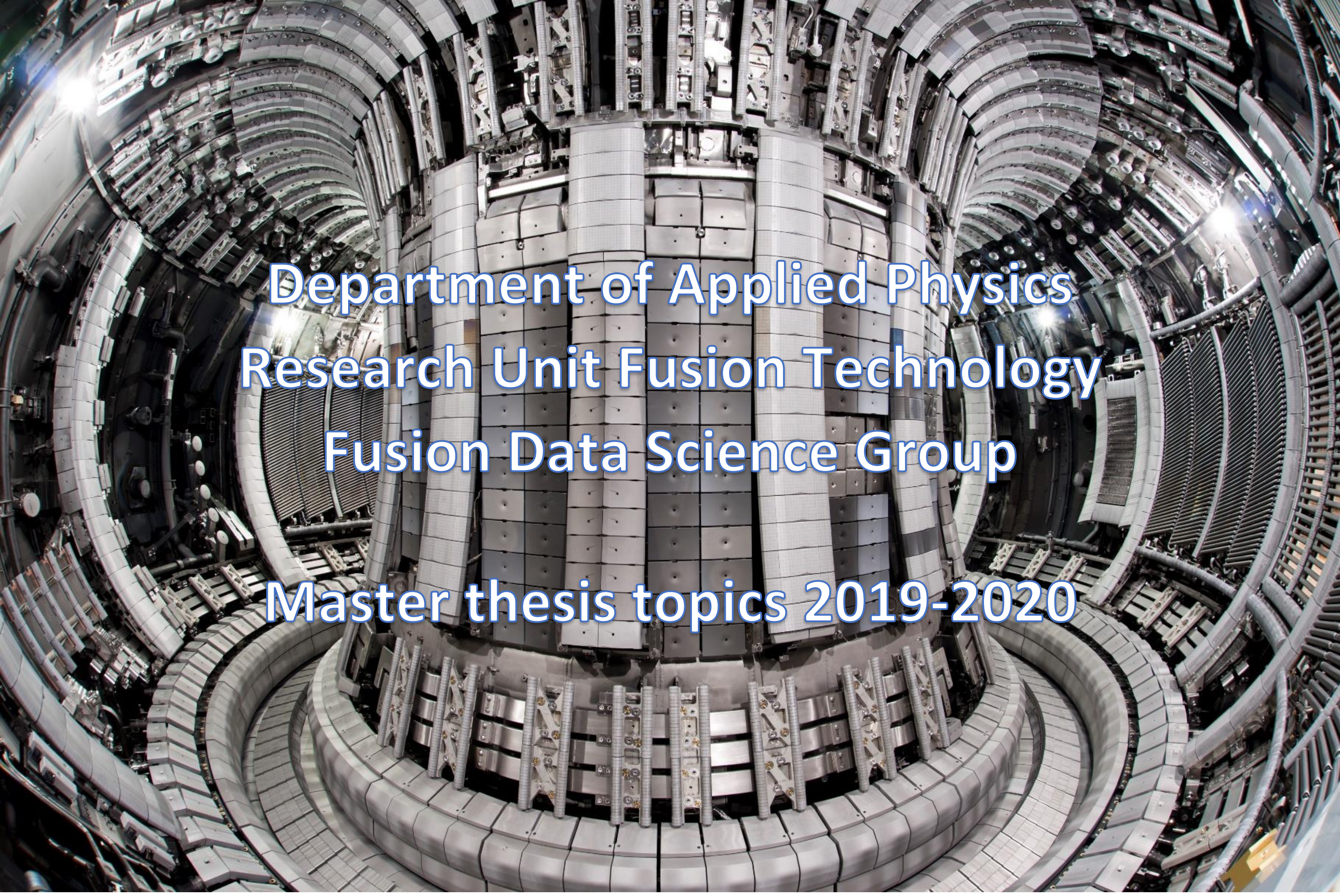

Department of Applied Physics
Research Unit Fusion Technology
Fusion Data Science Group

Master thesis topics 2019-2020

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The research on controlled thermonuclear fusion aims at providing stable, baseload electric power by creating “a star on earth”. Magnetic confinement fusion in tokamaks and stellarators is foreseen to result in clean and safe commercial power production by the second half of the century. ITER, the next-step device in this endeavor, is currently being constructed in France in the context of the largest international scientific collaboration ever.

With the large volumes of complex data being generated at experimental fusion machines around the world, there is a strong need for automated analysis using data science and big data methods. The UGent group specializes in machine learning and Bayesian inference applied to fusion experiments. Using powerful data science techniques, we study plasma confinement, magnetohydrodynamic instabilities, plasma turbulence, and we provide advanced data analysis for various diagnostics and machine subsystems. The goal is to describe important patterns in the data which can be exploited for increasing the physics understanding of fusion plasmas and for plasma control.

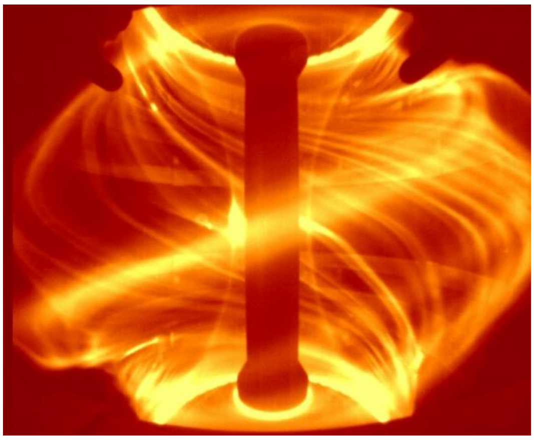
The master thesis topics introduced below cover part of the group’s research activities, in collaboration with the research institutes operating the tokamaks JET (Culham Centre for Fusion Energy, UK) and

ASDEX Upgrade (Max Planck Institute for Plasma Physics, Germany). The focus of each of the topics can be directed towards the numerical or physics aspects, depending on the student's interests. A research visit to each of the facilities also belongs to the possibilities.

Topic 1: Study of edge-localized instabilities in the JET tokamak

Edge-localized modes (ELMs) are magnetohydrodynamic instabilities that naturally occur in the boundary of tokamak plasmas in the high-confinement regime (H-mode). Acting as a pressure release valve, they lead to a quasi-periodic series of bursts of particles and energy escaping from the plasma (somewhat similar to coronal mass ejections in the sun). Depending on the plasma conditions, different types of ELMs can occur, some of which can be harmful to the machine or its performance. Active control of ELMs is therefore being investigated, using various techniques such as magnetic field perturbations or injection of cryogenic deuterium pellets. However, for reliable performance a better physical understanding of ELMs and the influence of control techniques is needed.

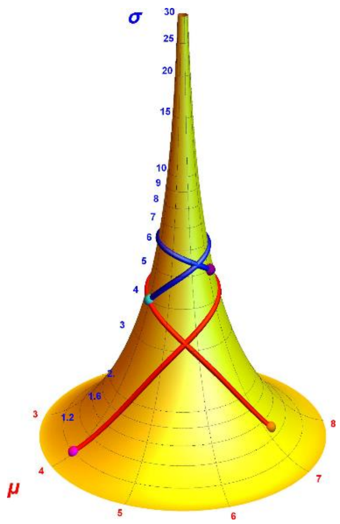
In this thesis the student will work on machine learning methods for automated ELM type identification based on probability distributions of their properties. In addition, the dependence of the distributions on plasma parameters will be studied. Depending on your interests, you can focus either on development of the methods, based on an exciting geometric approach to probability, and build a system that recognizes and analyzes ELMs at JET (and possibly ASDEX Upgrade). Or, you can contribute to implementation of the algorithms in a new (Python) computer code for ELM recognition that will be deployed at JET.



Plasma filament structures aligned along magnetic field lines, observed by fast cameras during an ELM event in the MAST spherical tokamak.

Topic 2. Prediction of plasma energy confinement for ITER using geodesic least squares

The study of the scaling of key physical quantities characterizing a system, in terms of a number of parameters that can be measured or controlled, is a widespread practice for unraveling the fundamental laws governing complex physical systems in many disciplines such as astronomy, biology, climatology and finance. In controlled nuclear fusion science based on magnetic confinement, scaling laws are essential for establishing design constraints and predicting the performance of fusion reactors. However, due to the complexity and heterogeneity of the data, robustness of the derived scalings is often an issue.



Geodesic curves on a surface representing the family of Gaussian probability distributions.

At UGent a new method has been developed, called *geodesic least squares* (GLS), to robustly quantify trends in physical systems by modeling the data as points in a curved probability space and seeking the shortest path (geodesic) between the modeled and observed probability distributions. The aim of this thesis is to use the GLS method for deriving critical scaling laws related to various plasma confinement properties in the international fusion device ITER, which is presently being constructed in Southern France. This involves selecting adequate probability models, calculating geodesic distances in the corresponding probability space, optimization of the scaling surface and prediction for ITER.

Topic 3. Predictive maintenance for fusion energy reactors through machine learning on hybrid data

In future fusion reactors it will be essential to avoid unexpected failures, which could result in supply interruptions. This means that any required replacements or maintenance activities will need to be detected early so that they can be scheduled in a repair plan. In this thesis, we investigate the potential of predictive maintenance using innovative data analysis techniques, to detect component failures before they happen (and fix them). This demands a continuous monitoring of the equipment using specialized sensors and identifying parameters that might indicate equipment failure. Any off-normal behavior of components may then be flagged in advance using anomaly detection techniques.

After studying the recent literature on multivariate white/grey/black-box approaches for predictive maintenance using a data-driven approach, various models based on decision trees, support vector machines or advanced neural networks will be trained and compared using real-world data from the JET device, the largest operational tokamak in the world (Culham Centre for Fusion Energy, CCFE, UK). An important challenge will be the sheer size of the data: on JET there are approximately 70,000 signals, including plasma parameters and sensor data from supporting equipment. Particular failures that can be studied during the thesis work include

A turbopump at JET with a broken blade due to an unexpected failure.

- current switches on the pulsed power supplies, especially on the central solenoid,
- the real-time data acquisition system,
- turbopump damage,
- water leaks in the neutral beam injectors.

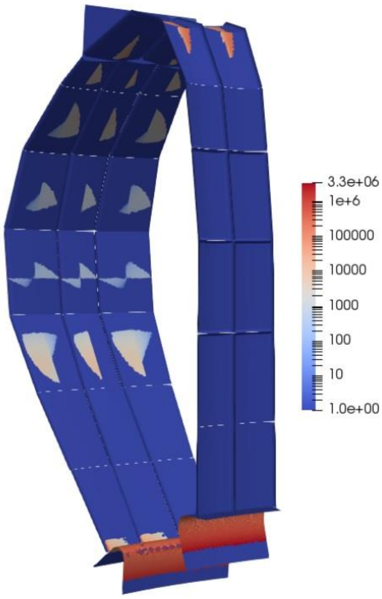
The specific feature studied in this thesis will be agreed with the student, but the methodology will be the same for all.

A research stay at CCFE is encouraged in the framework of this thesis (several opportunities for travel support can be explored).

Topic 4. Uncertainty quantification in heat load modeling for the JET deuterium-tritium campaign

Modeling of heat load deposition is an important tool for design and safe operation of a fusion device. Particularly sensitive is the alignment of the tiles in the first wall, as small protrusions may be subjected to large heat loads, potentially causing damage to the tiles. Therefore, it is essential to determine the main causes for uncertainty in the first wall geometry and quantify the effect on the expected heat loads. This is the topic of *uncertainty quantification*, a field using methods of probability and machine learning that is rapidly gaining interest in modeling and manufacturing. One of the main challenges in this domain lies in the computational cost of typical modeling codes, which in practice often excludes uncertainty propagation using a Monte Carlo approach based on a simple sampling scheme.

In this thesis work, after studying the main uncertainty quantification techniques in the literature, an application will be targeted to heat deposition modeling in the JET tokamak (Culham Centre for Fusion Energy, Oxfordshire, UK). The largest tokamak in the world, JET is currently a focus of attention of the fusion community, in view of the upcoming experimental campaign with plasmas consisting of a mixture of deuterium (D) and tritium (T). The D-T mixture is the fusion fuel of the future, and the JET experiments aim at setting a new record for fusion power production. One of the ingredients for success will be a reliable predictor of in-vessel surface temperatures, which is fast enough to run in between plasma pulses. This will help to avoid crossing operational limits regarding heat deposition. The thesis work will contribute to this goal by implementing a surrogate model, e.g. based on a neural network, enabling efficient uncertainty quantification for the expected heat loads. The surrogate model will emulate the specialized SMARDDA code, coupled to the ANSYS™ software, for calculating temperature rises due to power deposition in a detailed model of the JET first wall.



Visualization of a typical heat flux distribution for ideal DEMO geometry, generated with SMARRDA.

A research stay at CCFE is highly encouraged in the framework of this thesis (several opportunities for travel support can be explored).

Recent picture of the ITER construction site, with the setting sun reflected on the assembly hall.