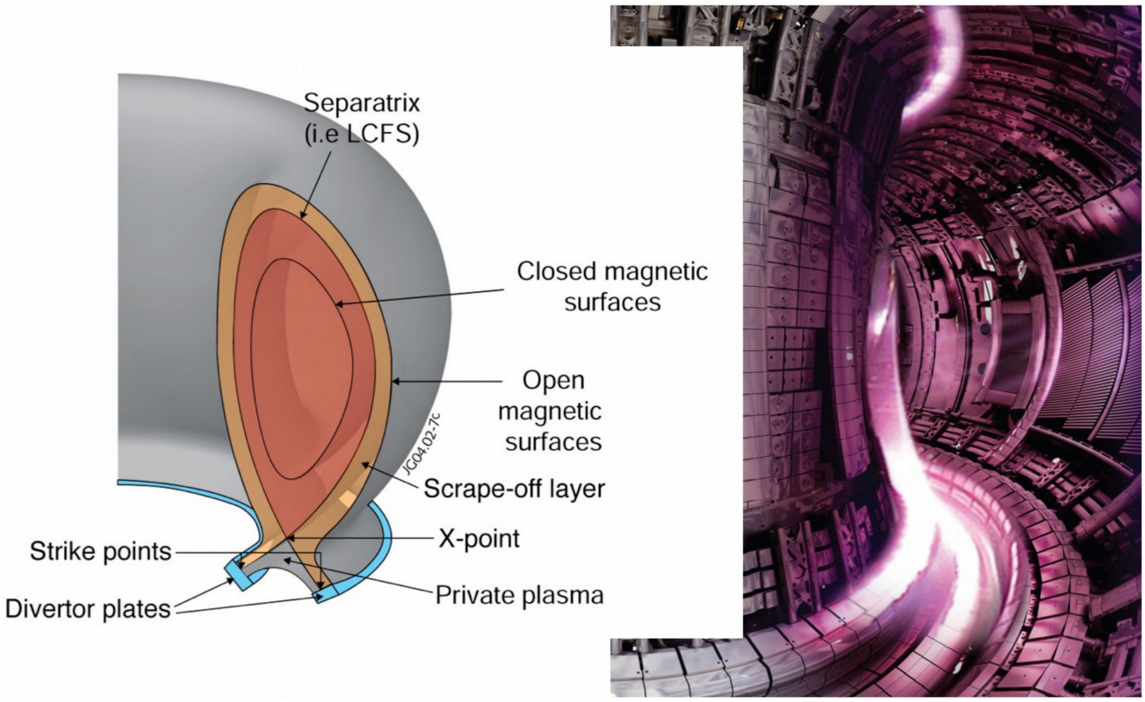
Fusion and plasma physics – summer project proposals

The Fusion and Plasma Physics research group is seeking to recruit interested and motivated students for the summer 2023 period. We offer topics suitable both for Bachelor's theses and special assignments, potentially leading to Master's theses. Further information about the group itself can be found from our website: https://www.aalto.fi/department-of-applied-physics/fusion-and-plasma-physics. The overview of the projects will be presented in the department common info session.



Collisional-radiative models in fusion plasmas (instructor: Ray Chandra)

A CRM (collisional-radiative model) is a mathematical model that can be used to calculate the effective ionization and recombination rate of hydrogen gas in a plasma. The equation governing a CRM describes the rate of change of densities of hydrogen atoms and ions in a plasma, taking into account the various collisional and radiative processes that can affect the ionization and recombination rates. By solving this equation numerically, it is possible to calculate the population densities of excited hydrogen atoms under a given set of conditions, such as the plasma temperature and density. The cumulative densities of excited hydrogen atoms along with the non-excited atom and ion species ultimately governs the effective ionization and recombination rate of hydrogen. These effective rates have utilities in other plasma models that fill important roles in plasma physics, such as astrophysical studies or the optimization of a fusion reactor.

The summer project involves the use of a CRM model with the programming languages Python and Fortran. The first objective is to use the CRM model to investigate the impact of factors, such as temperature, density, and the number of excited levels, to the effective ionization and recombination rate of hydrogen. The student is expected to learn the basic physics knowledge in a CRM during the first objective. Once sufficient knowledge is demonstrated, there are two different objectives that the student can approach. The first option is to apply that knowledge and use CRM for other elements, such as helium or hydrogen molecules. The second option is to learn the application of a CRM in a photon tracing code. In the second option, the student will be expected to also learn the basic physics of radiation-as-particle transport. The student will present their results in a final report detailing their knowledge and outlook of their results. The project requires amble knowledge in atomic physics, thus is more suitable for third- and fourth-year students.

Simulations of deposit layer formation in JET (instructor: Roni Mäenpää)

The Joint European Torus (JET), the world's largest operational tokamak, has wall components made of beryllium, tungsten, and Inconel alloy. Plasma-wall interactions inevitably result in some erosion of the wall materials, which dilute the fusion plasma and cause a cooling effect via radiation. Certain regions of the wall are eroded faster than material is deposited onto the wall by the plasma, whereas layers of deposited material are formed in other regions. Understanding the erosion and deposition processes is important for predicting the lifespan of the wall components and for avoiding contamination of the fusion plasma. The proposed project uses the Monte Carlo simulation code ERO2.0 to predict the erosion, transport, and deposition of JET wall materials in several plasma scenarios representative of typical JET experiments. The predicted deposition rate of each material is used to estimate the deposit layer thickness and the material composition as functions of time at different wall locations. The expected thickness and composition of deposit layers is compared to experimental observations based on post-mortem tile analysis from three JET experimental campaigns. Prior knowledge in the programming language Python is desired to develop post-processing analysis tools. The project is suitable for students at Bachelor's level.

Analytic models of the scrape-off layer in tokamaks for hydrogenic and helium plasmas (instructors: David Rees, Mathias Groth)

Predicting the plasma and neutral conditions in the scrape-off layer in tokamaks – the outermost plasma layer connecting the burning plasma in the core to the device vessel wall – is one of the most critical, yet challenging tasks in fusion energy research and development. Analytic models exist; however, the complexity of the scrape-off layer often calls their validity into question. These models are primarily developed for hydrogenic plasmas, but operation in helium plasmas is also foreseen in future devices during their plasma commissioning phase.

In the proposed project, the physics of the scrape-off layer is reviewed and the analytic two-point model for (singly ionized) hydrogenic plasmas derived. The two-point model will be extended toward a multi-ion species of helium, and the need for including both singly and doubly ionized helium assessed using ionization-recombination balance models. The predictions from the two-point model are compared to more sophisticated numerical models to determine the validity of the two-point model. Prior knowledge in the programming language Python is desired to compare the models. The project is suitable for entry-level Bachelor's students.

Prediction of scrape-off layer radiation in tokamaks (instructor: Mathias Groth)

Radiation in the scrape-off layer in tokamaks plays a critical role in mitigating the power loads originated in the core of burning fusion plasmas below the thermo-mechanical properties of the plasma-facing components. Predicting and validating plasma radiation is one of the most critical tasks in designing plasma scenarios in future fusion devices, and dedicated experiments in current tokamaks, such as ASDEX Upgrade and JET, are performed to characterize the radiation profiles in these devices.

In the proposed project, the physics of radiation in fusion plasmas is reviewed, and its inclusion in numerical models discussed. Based on existing simulations, the Bremsstrahlung and line radiation profiles are predicted and compared to actual measurements in hydrogenic and helium plasmas. The project will introduce the student to the synergy of plasma physics and atomic and molecular physics, the codependences of ion and photon fluxes, thus providing further insight in plasma-wall interaction. The project is suitable for advanced-level Bachelor's or M.Sc. level students and requires prior knowledge in Python programming.

Neutron transport simulations of HELIAS stellarator using Serpent code (instructor: Antti Snicker)

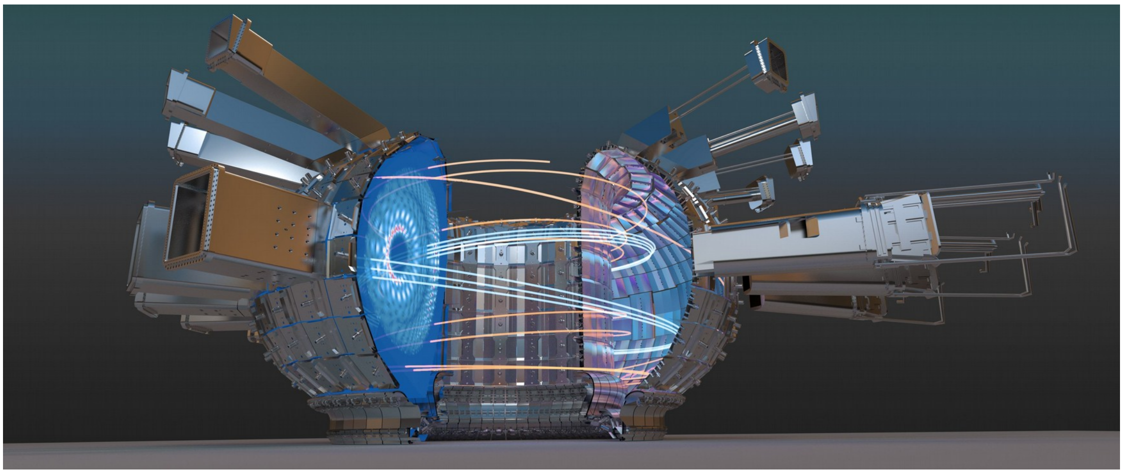
Thermonuclear fusion can be achieved using so-called magnetic field confinement. In this approach, fusion plasma is confined using strong magnetic fields, that guide movement of all charged particles and keep them inside the vacuum vessel. A stellarator is a device in which external field coils generate the entire magnetic field. A reactor candidate stellarator, HELIAS, is being designed within EUROfusion. One key aspect of the reactor design is understanding how the neutrons born in the fusion reactions transport inside the device. Key research questions are, e.g., how much tritium (an isotope needed to sustain the fusion burn) can be bred in the HELIAS blanket? How thick a blanket is needed to shield the field coils from neutrons? These can be answered using the Serpent coil to calculate the transport of neutrons.

Investigations of non-standard NBI density and current drive in tokamaks (instructor: Antti Snicker)

Neutral beam ions (NBI) are ions with substantially larger energy than bulk plasma ions. These ions can both heat the plasma and drive part of the toroidal current needed in tokamak plasmas. However, NBI-heated ions are also undergoing various transport processes. Typically such processes happen in the 6-dimensional phase-space containing both real space and velocity space. Often transport processes are also local, happening only in part of the phase space. This can distort the original distribution function. Since the current drive depends on the velocity space of the distribution function, it is interesting to study how different transport processes redistribute NBI ions in velocity and real space, leading to differences in density and current drive. In particular, here we are interested in transport caused by various MHD instabilities and CX processes. During the work, the student will implement necessary diagnostics in ASCOT5 and then analyze the result.

ASCOT simulations of NBI distribution functions in JT-60SA tokamak (instructors: Seppo Sipilä, Antti Snicker)

One of the most interesting new fusion devices starting its operation in near future is JT-60SA, a tokamak being built in Japan and being operated in collaboration between Japan and Europe. One key aspect being studied in this machine is the high-energy NBI systems mimicking those of ITER. In particular, it can be expected that these beams are capable of driving various instabilities that can then cause the transport of these ions. In order to understand and predict this phenomenon, the key ingredient to be accurately modeled is the NBI distribution function. Our Monte Carlo code ASCOT can do this job. The result can then be used to model the stability of the energetic particle-driven waves. In this work, gradients of the distribution functions are needed. Therefore, the original calculation of the distribution function needs to be done carefully enough so that the distribution function is smooth enough for taking gradients. This works tests methods generated to solve this problem.



GENE simulations of isotope effect in JET tokamak (instructors: Francis Albert, Timo Kiviniemi)

The effect of hydrogen isotopes on plasma confinement is experimentally well-known. However, the understanding the effect of isotopes on density peaking and particle transport coefficients requires more investigations for which gyrokinetic and transport codes can be used. The first task of the project is to run gyrokinetic simulations using the GENE code for JET tokamak discharges to validate the particle transport coefficients obtained from simulations with experiments. Next step is to understand the discrepancy (if any) between simulations and experiments and study the isotopic dependence on particle transport coefficients.

GENE (Gyrokinetic Electromagnetic Numerical Experiment) is an open source plasma microturbulence code which can be used to efficiently compute gyroradius-scale fluctuations and the resulting transport coefficients in magnetized fusion/astrophysical plasmas. To this aim, it solves the nonlinear gyrokinetic equations on a fixed grid in five-dimensional phase space (plus time). GENE simulations runs on super computers using between a few to tens of thousands of CPU cores. Data from simulations is usually analysed by using the GENE diagnostic tool written in IDL language.