How to improve plasma diagnostics on Wendelstein 7-X with Collective Thomson Scattering

The growth of the world's energy consumption is a global issue with serious environmental implications. Nuclear fusion - the reaction powering the stars - is one of the solutions that are currently explored. It is a clean, inexhaustible and inherently safe energy source. However, it is incredibly complicated and to achieve it in terrestrial conditions the fuel needs to be heated to extreme temperatures.

Nuclear fusion happens at 200 million degrees Celsius, whereby the mixture is in a state of a fully ionized gas - a plasma - and it cannot be contained by a physical wall. For this reason the fusion research led to something called magnetic confinement where the plasma is confined to a typically toroidal region in space by means of strong magnetic fields.

Research in magnetic confinement nuclear fusion for energy generation has led to two advanced concepts of confinement: the tokamak and the stellarator. Both concepts are based on confinement of a plasma of hydrogen isotopes deuterium and tritium in toroidal geometry. While the tokamak is furthest developed in terms of performance, the stellarator offers an important advantage over the tokamak – steady state operation.

The most advanced and the World's only optimized stellarator, the Wendelstein 7-X (W7-X) experiment in Greifswald (Germany), came into operation in 2015 with the goal to explore the viability of the optimized stellarator concept as a fusion reactor. The main objective of the W7-X experiment is to demonstrate reactor relevance of stellarators by confirming the effectiveness of the optimization and achieving steady state operation of 30 minutes.

Whether this objective has been achieved is a question which can be answered once the data gathered by the means of plasma diagnostics are analysed and evaluated. Most of the diagnostic methods are based on observing the particles and radiation coming out of the plasma. Various phenomena such as absorption, reflection, refraction, as well as ionization of neutral particles, particle collisions make diagnostics challenging to operate and make data analysis difficult as many effects and uncertainties need to be accounted for.

The work of Abramovic concerned the development of a powerful microwave diagnostic unique in its capability to measure a number of important plasma parameters simultaneously - collective Thomson scattering (CTS). A CTS measurement results in a spectrum from which values of desired plasma parameters can be inferred.

Abramovic developed a model which allows calculation of synthetic CTS spectra based on a set of input parameters. By integrating it into a so-called Bayesian scientific framework it allows one to calculate posterior probability distributions of input parameters. eCTS has successfully been used to analyze the first CTS spectra obtained on W7-X.

The work also furthers CTS theory by extending the set of parameters measurable by the CTS diagnostic to include the radial electric field and enables exploration of anisotropic temperature effects. Finally, the work explores experimental challenges hindering optimal performance of

CTS as well as data analysis related challenges which stand in the way of using this diagnostic to its full potential.