7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

Anomalous electron diffusion in magnetized plasma with magnetic islands and field stochasticity

Evdokiya Kostadinova[1], Bradley Andrew[1], Jessica Eskew[1], Dmitri Orlov[2], Mark Koepke[3], Frederick Skiff[4], and Max Austin[5]
[1] Physics Department, Auburn University, [2] Center for Energy Research, UC San Diego, [3] Department of Physics and Astronomy, [4] West Virginia University, Department of Physics and Astronomy, University of Iowa, [5] Institute for Fusion Studies, The University of Texas at Austin
e-mail (speaker): egk0033@auburn.edu

Energetic electrons (EEs) in magnetized plasmas are sub-populations of particles whose energy is orders of magnitude higher than the bulk electrons. These particles are known to exhibit anomalous diffusion in the cross-field direction, which results in non-Maxwellian energy distribution functions. While EEs are ubiquitous in laboratory conditions (tokamaks and stellarators) and in space plasma (the solar wind and the Earth's magnetotail), their origin and dynamics are poorly understood. Here we investigate experimentally how the production, trapping, and release of energetic electrons in magnetized plasma are affected by the features of the magnetic field topology in magnetized plasmas using data from the DIII-D tokamak [1] and a Fraction Laplacian Spectral (FLS) model [2]. Specifically, we focus on the role of magnetic island chains and regions of magnetic field stochasticity.

In the examined DIII-D experiments [1], coil perturbations are used to create and manipulate islands at desired flux surfaces, while electron cyclotron heating and current drive (ECH/ECCD) pulses are employed to 'tag' electrons within various locations inside and outside the island chains. The properties of suprathermal electrons are determined from Thomson Scattering, electron cyclotron emission, gamma ray imaging, and scintillator (hard X-ray) measurements. The experiments examine how the distribution of suprathermal electrons changes as a function of island width, location, structure, and dynamics.

Two types of energetic particles are distinguished and discussed: nonrelativistic suprathermal electrons and relativistic runaway electrons. The magnetic field topology in each discharge is reconstructed with field line tracing codes, which are also used to determine the location and scale of magnetic islands and stochastic regions. Comparison of simulations and experiments suggests that suprathermal transport is suppressed when the tagging is performed at a smaller radial location than the location of the q=1 island chain and enhanced otherwise. We further demonstrate that increasing the width of the stochastic region within the edge plasma yields enhancement of the suprathermal electron transport.

To understand the physical mechanisms leading to anomalous electron diffusion observed in these experiments, we employ a Fraction Laplacian Spectral (FLS) model [2]. In the FLS model, the probability for anomalous electron transport as a function of magnetic field topology is determined from the spectrum of the corresponding Hamiltonian. We construct Hamiltonian operators corresponding to the magnetic field topology in the examined DIII-D experiments. Nonlocal interactions due to magnetic islands are modeled by a fractional Laplacian operator, while random fluctuations of the field due to coil perturbations are represented by a stochastic potential term in the Hamiltonian.

The spectral properties of each Hamiltonian are investigated for fractions representative of each diffusion regime. Comparison of these calculations to DIII-D data reveals the presence of at least two types of EEs: runaway electrons, best described by a Lévy process, and suprathermal, but non-relativistic, electrons, best described by trapping with nonlocal jumps. As these findings are in agreement with experimental results, we propose that the FLS approach can be used as a powerful reduced model for the study of nonthermal electron transport in magnetized plasmas.

[1] Kostadinova, E. G., et al. *(submitted to JPP)*, arXiv preprint arXiv:2303.02009 (2023).
[2] Padgett, J. L., et al., J. Phys. A. **53.13** (2020): 135205.