Analysis of fast ion induced instabilities in tokamak plasmas

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Abstract

Nuclear fusion is a promising energy source of the future. One possible way to achieve reliable energy production from fusion reactions is to confine the high temperature deuterium-tritium fuel by magnetic fields. In magnetic confinement fusion devices like tokamaks, it is crucial to confine the high energy fusion-born helium nuclei (α-particles) to maintain the energy equilibrium of the plasma. However, super-thermal energetic ions can excite various instabilities which can lead to their enhanced radial transport. Consequently, these instabilities may degrade the heating efficiency and they can also cause harmful power loads on the plasma-facing components of the device. Therefore, the understanding of these modes is a key issue regarding future burning plasma experiments.

One of the main open questions concerning energetic particle (EP) driven instabilities is the non-linear evolution of the mode structure. In this thesis, I present my results on the investigation of β-induced Alfvén eigenmodes (BAEs) and EP-driven geodesic acoustic modes (EGAMs) observed in the ramp-up phase of off-axis neutral beam injection heated plasmas in the ASDEX Upgrade tokamak. These modes were well visible on several line-of-sights of the soft X-ray cameras which made it possible to analyse the time evolution of their spatial structure.

In order to investigate the radial structure, the mode amplitude has to be determined on different line-of-sights. I developed an advanced amplitude reconstruction method which can handle the rapidly changing mode frequency and the low signal-to-noise ratio. This method is based on short time Fourier transform which is widely applied in the thesis, because it is ideal to investigate the time evolution of transient wave-like phenomena.

The radial structure analysis showed that in case of the observed downward chirping BAEs the changes in the radial eigenfunction were smaller than the uncertainty of the measurement, while in case of rapidly upward chirping EGAMs the analysis shows shrinkage of the mode structure. These experimental results are shown to be consistent with the corresponding theory.