Kinetic Alfvén waves and gyrokinetic fast-ion driven modes in fusion plasmas

C. Slaby[1], M. Borchardt[1], R. Kleiber[1], A. Könies[1], H. Leyh[1], A. Mishchenko[1], K. Rahbarnia[1], A.v. Stechow[1], H. Thomsen[1], S. Vaz Mendes[1] and the Wendelstein 7-X Team[2]

[1] Max Planck Institute for Plasma Physics, Wendelsteinstr. 1, 17491 Greifswald, Germany

e-mail (speaker): christoph.slaby@ipp.mpg.de

In this contribution, we will present an overview of kinetic Alfvén waves and fast-ion-driven Alfvén eigenmodes (AEs) related to fusion plasmas. The focus will be on nonlinear simulations of their interaction with plasma particles. The arising physics is characterized by interesting nonlinear dynamics influenced by collisions. Observations of Alfvén-wave activity measured in the past experimental campaigns of the stellarator Wendelstein 7-X will be shown.

We will start with kinetic Alfvén waves (KAWs) in slab geometry as such a case lends itself well to illustrating the basic physics of KAWs. We will focus on how KAWs can be affected by collisions and show modifications of the Landau resonances in velocity space as well as modifications to the dispersion relation [1].

Next, we will turn towards the kinetic modification of AEs by fast particles in more relevant tokamak and stellarator equilibria. The main focus will be on the nonlinear saturation dynamics of AEs in the presence of collisions [2]. We will calculate the nonlinear saturation levels of the AEs, which are of crucial importance for the fast-ion transport in e.g. a future fusion reactor which needs to have good fast-ion confinement. This transport aspect of the nonlinear wave-particle interaction is studied with a multi-mode model in which the combined transport of several eigenmodes can be studied in a single simulation. We will show for a tokamak case how multiple AEs in the same simulation cause more transport than if the modes were considered individually.

Further, we will address the issue of nonlinear frequency chirping which, in experiments, has also been found to coincide with periods of enhanced fast-ion transport [3]. We will show, using a perturbative model, how frequency chirping (see Figure 1) can be affected by collisions [4], but also present fully gyrokinetic frequency chirping (without any simplifying approximations) which is numerically much more challenging to simulate.

For the interpretation of the simulated frequencies of fast-ion-driven AEs, the comparison with the Alfvén continuum is essential for understanding why certain modes (and not others) are become destabilized. The same applies to experimental measurements of frequencies, which should be compared to the continuum with its gap structure. Usually, those continua are calculated from MHD equations, but kinetic extensions are possible [5, 6]. We will show that the EUTERPE code also offers the possibility to calculate a fully gyrokinetic continuum in a self-consistent particle-in-cell simulation using advanced signal processing tools [7]. A radial electric field, shifting the frequencies of the continuum branches, can be taken into account [8].

The talk will conclude with an overview of Alfvén-wave activity that has been observed in past experimental campaigns of the Wendelstein 7-X stellarator [9]. These experimental observations are still being analyzed theoretically with respect to their driving force. This analysis includes several ingredients such as the gradients of the plasma profiles, the general turbulence level and the magnetic configuration.

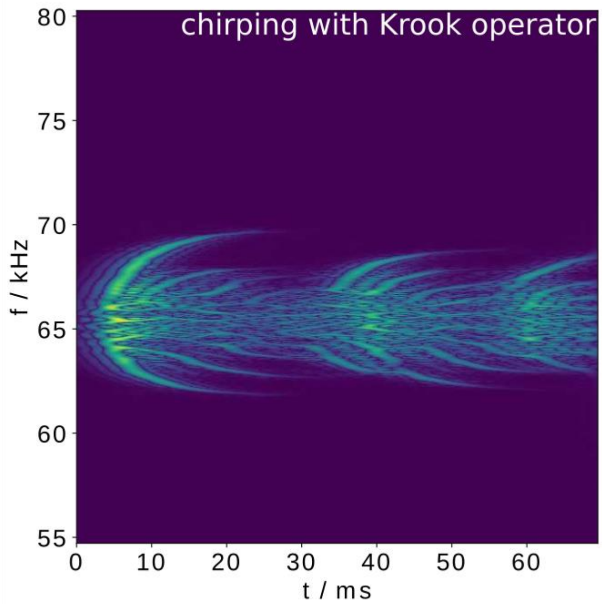

Figure 1. Influence of a Krook operator on the nonlinear frequency chirping. The Krook operator periodically rebuilds the distribution function of the fast ions and thus leads to periodic chirping events. Adapted from [4].

References

[1] C. Slaby *et al* 2017 *Comp. Phys. Comm.* **218** 1-9

[2] C. Slaby *et al* 2018 *Nucl. Fusion* **58** 082018

[3] M. Podestà *et al* 2014 *Plasma Phys. Control. Fusion* **56** 055003

[4] C. Slaby *et al* 2019 *Nucl. Fusion* **59** 046006

[5] C. Slaby *et al* 2016 *Phys. Plasmas* **23** 092501

[6] Ph. Lauber 2015 *Plasma Phys. Control. Fusion* **57** 054011

[7] R. Kleiber *et al* 2021 *Plasma Phys. Control. Fusion* **63** 035017

[8] A. Könies *et al* 2020 *Phys. Plasmas* **27** 122511

[9] K. Rahbarnia *et al* 2021 *Plasma Phys. Control. Fusion* **63** 015005

[2] see author list of T. Klinger *et al* 2019 *Nucl. Fusion* **59** 112004