Identification of edge-localized instabilities in nuclear fusion plasmas using pattern recognition techniques

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At sufficiently high heating powers, fusion plasmas undergo a transition to a high confinement (H-mode) regime, which is the reference scenario for ten-fold power multiplication inductive operation in the next-step fusion device ITER. H-mode is characterized by steep pressure gradients in the edge region which leads to magnetohydrodynamic (MHD) instabilities called edge-localized modes (ELMs). ELMs are intense, short duration, repetitive events that result in sudden expulsion of energy and particles from the plasma edge. On the one hand, large type I ELMs pose a serious concern as they can cause high transient heat loads on the plasma-facing components (PFCs). On the other hand, controlled ELMs are crucial for regulating the core concentration of impurities, in particular tungsten (W), which is produced by interaction of the plasma with the PFCs.

A key challenge is to provide a quantitative distinction between the different observed classes of ELMs and to relate this classification to the physical processes responsible for them. In this work, a pattern recognition-based classification scheme is developed for the characterization and automatic classification of ELM types, with the aim to distinguish ELM classes in a practical, fast and standardized way. The first step entails the construction of probability distributions of ELM properties, namely waiting times, energy losses, as well as global plasma parameters. In the next step, we employ the mathematical framework of information geometry, which allows the calculation of the geodesic distance (GD) as a natural and theoretically well-motivated similarity measure between probability distributions. The developed distance-based classifier is then applied for the classification of type I and type III ELMs with success rates up to 96%. The presented system demonstrates the advantage of considering complete probability distributions of plasma quantities in contrast to mean values and at the same time provides a fast, high-accuracy classification of ELM types which significantly reduces the effort of ELM experts in identifying ELM types. Further, the classification results can potentially contribute to physical understanding of ELMs and optimization of control and mitigation schemes.