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Stochastization effects in magnetized 3D plasmas

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In magnetic confinement fusion plasmas, the introduction of 3D magnetic fields often leads to the creation of magnetic island chains on resonant surfaces and – subsequently – the creation of stochastic magnetic field regions when those island chains overlap. This phenomenon is commonly observed in high-beta operation in Stellarator configurations and in the edge plasma of Tokamaks operated with the application of resonant magnetic perturbations (RMP).

The local diffusion of magnetic field lines induced by the stochastization has been characterized early on through the analysis of. In confinement fusion, this analysis is substantially complicated by the interaction of the field line diffusion with diffusive, convective, and turbulent transport processes in the confined plasma, as well as the distortion of the initial flux surfaces by nonresonant perturbations.

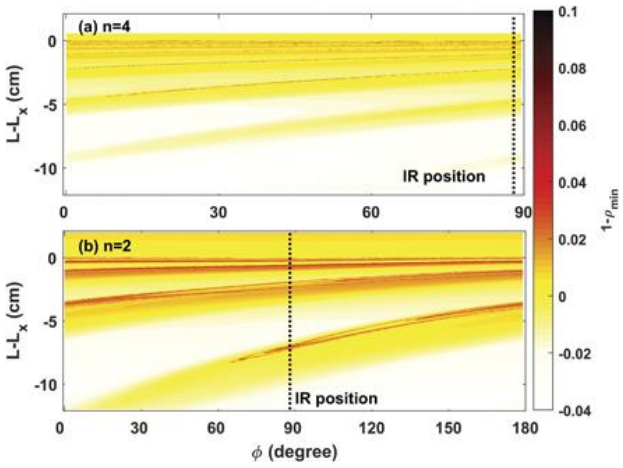

Figure 1 Heat load splitting under RMP application on the EAST divertor [1]

A common observation associated with magnetic field stochastization is the appearance of secondary heat load patterns on the divertor (fig. 1), and the formation of lobe-like structures in upstream connection length structures (fig. 2). These patterns hint at the presence of attractors in the stochastic domain which shape the heat flow from the upstream regions onto the divertor. This is in good agreement with the structured surface structure of the as-designed unperturbed divertor field.

Around the field line of an X-point, the derivative of the Poincare map can be employed to construct field-aligned surfaces from the X-point, which represent the primary

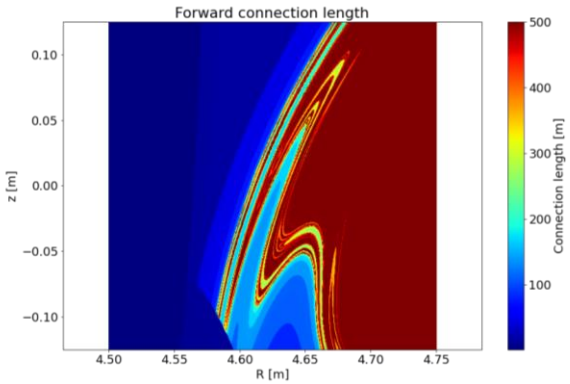

Figure 2: Forward connection length distribution near the X-point of a stochastic edge configuration on Wendelstein 7-X, based on equilibria from [2]

directions of heat conduction in the forward- and backward-direction. Under the influence of a perturbation field these manifolds can still be constructed, but their shape is substantially distorted, forming lobe structures near the X-point that mirror the distorted X-point structures and the secondary heat loads observed on divertor targets.

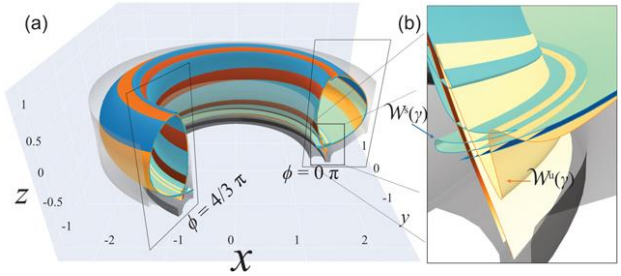

Figure 3 Field-aligned surfaces constructed from the X-point and their perturbation by an external RMP field in the EAST Tokamak, overall (a) and near the X-point cycle (b) [3]

These field-aligned surfaces appear to be strong candidates for the observed secondary heat load patterns present during RMP application, and might also prove valuable to separate geometric properties of stochastic edge topologies from localized transport effects.

References

[1] Manni Jia et al 2021 Nucl. Fusion 61 106023
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[3] Wenyin Wei and Yunfeng Liang 2023 Plasma Sci. Technol. 25 095105