5th Asia-Pacific Conference on Plasma Physics, 26Sept-1Oct, 2021, e-conference

Causality in spontaneous edge transport barrier onset

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The observation of rapid core confinement improvement upon favourable modifications of edge operating conditions has been a nagging source of puzzlement for experimentalists investigating conditions for a lasting source of fusion energy in tokamaks. The transport properties of drift-wave turbulence and the interaction of the confined plasma with its material boundaries have long been recognised as essential to the resolution of this conundrum. Key aspects of the turbulent dynamics in the plasma edge are poorly quantified, owing to the disparity of temporal and spatial scales and the inadequacy of performing scale separations. We have reported on a possible resolution of the so-called `shortfall' conundrum through nonlinear destabilisation (turbulence spreading) of the linearly stable edge upon incorporation of a simplified yet robust plasma—boundary interface. Another central manifestation from core—edge—SOL interplay is the spontaneous emergence of a stable and localised transport barrier at the closed/open field line transition, possible prelude to the formation of a pedestal. This observation, from the primitive flux-driven equations is notable in its own right yet more interesting is the possibility to discuss the causal chain of events that leads to this spontaneous onset of an edge transport barrier. To this end, we systematically apply the so-called ``Transfer Entropy" (TE) technique to the gyrokinetic vorticity equation inferred from the actual flux-driven computations with limiter boundary conditions in the last 5% inside the last closed flux surface. The TE algorithm is imported from information theory and provides a robust and generic tool to assess causal inference in complex time series datasets. An example is shown below where information transfer is estimated between vorticity and a "field advection", in GYSELA. Remarkably, Reynolds stresses are found to be significant yet not the dominant players as possibly expected in the process of barrier onset. Diamagnetic currents are found to play a central role, this fact not often emphasised. This stresses the role of pressure inhomogeneities and finite Larmor radius (FLR) effects in barrier build-up. Connection to turbulence spreading (especially from separatrix to core) is central and discussed. Importance of FLR effects could have interesting side effects, possibly on I-mode or H-mode accessibility as different isotopes or different classes of particles differently contribute to vorticity (shear) production. We precisely discuss these findings, precise enough to challenge theoretical frameworks, improve our understanding of underlying mechanisms of edge barrier onset and provide important guidelines for reduced modelling.

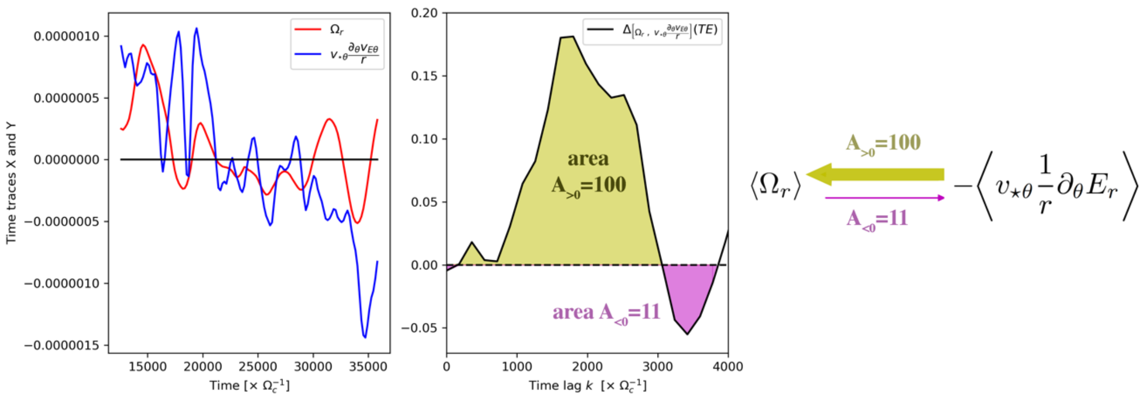

Figure 1. Causality, as inferred from the application of the TE algorithm to actual time series from flux-driven gyrokinetic computations near the magnetic separatrix, at inception of an edge transport barrier. Transfer of information towards and from vorticity Ω_r (flow shear) is scrutinised, based on the structure of the vorticity equation. The above illustration depicts as an example steps to infer a diagrammatic representation of information flow, its directionality and strength.