Suppression of core turbulence by profile shaping in Wendelstein 7-X

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In the Wendelstein 7-X magnetic confinement experiment, a reduction of ion-scale turbulent density fluctuations as well as anomalous impurity diffusion is associated with a central peaking of the plasma density profile. These effects correlate with improved confinement and appear largely due to a reduction of anomalous transport as the change in neoclassical transport is shown to be small. A decrease of turbulent heat flux with increased density gradients is in agreement with nonlinear gyrokinetic simulations, and has been attributed to the unique geometric optimization of W7-X that limits the severity of trapped electron modes.

Introduction The development of magnetic confinement concepts towards a fusion reactor crucially relies on a comprehensive understanding and control of particle and energy transport processes. Transport based on binary collisions and drifts is generally not sufficient to describe the large transport coefficients inferred from experiments. Particularly in tokamaks, radial transport based on microturbulence driven by gradients of the kinetic plasma profiles, i.e. electron and ion temperature as well as plasma density, dominates radial plasma losses during steady-state operation and limits the central plasma parameters (for a review see [1]). In low-beta plasmas, three electrostatic instabilities govern turbulence, namely the electron and ion temperature gradient (ETG/ITG) and density-gradient-driven trapped electron modes (TEM). These are characterized by their respecitve critical gradient thresholds above which turbulent fluxes rapidly increase. In tokamaks, it is commonly found that while ETG and ITG are stabilized by an increasing density gradient, TEM activity strongly increases and effectively prevents density profiles from steepening further [2, 3]. This effect is commonly called profile consistency, resilience or stiffness, and has been reproduced by nonlinear kinetic turbulence simulations.

The magnetic geometry of the Wendelstein 7-X (W7-X) stellarator has been tailored for low NC transport [4, 5], which allows transport driven by microinstabilities to play a significant role in the regulation of particle and energy fluxes across the confining magnetic field. This paper reports core density turbulence investigations in the W7-X stellarator and demonstrates that in peaked density profile scenarios, ion-scale turbulence and its associated transport is suppressed, supporting improved plasma confinement.

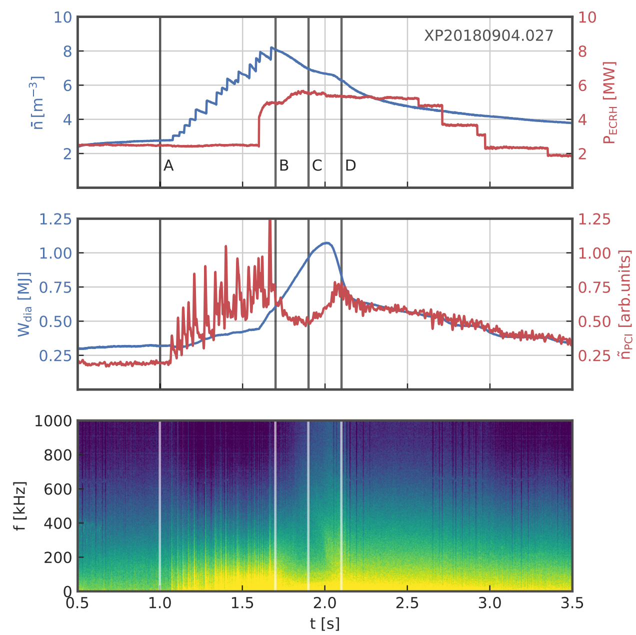

FIG. 1. W7-X experiment overview showing the line-integrated density $\bar{n}$ and heating power P_{ECRH}, the line-integrated density fluctuations $\tilde{n}$ measured by PCI and diamagnetic energy W_{dia}, and a spectrogram of PCI fluctuations. Time points A-D indicated by vertical lines.

Turbulence evolution in peaked density scenarios Plasma density peaking in W7-X is influenced both by cryogenic pellet injection [6] or neutral beam injection (NBI) [7]. In both discharge scenarios discussed here, initial plasma breakdown occurs by electron cyclotron heating (ECH) only. For the pellet-fueled scenario (Fig. 1) a