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Gyrokinetic simulations of core turbulence in a reference JT-60SA scenario

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The so-called reference scenario 2 [1] of the JT-60SA tokamak is studied with gyrokinetic GENE simulations. The scenario features 41 MW of combined neutral beam heating and electron cyclotron heating, and a high predicted ratio β of the plasma kinetic to magnetic pressure.

Profiles produced by the ACCOME and TOPICS predictive transport modeling [2] were used as an input for GENE. The local linear and nonlinear modeling was carried out mainly at ρ_{tor}=0.5, where ρ_{tor} corresponds to the square root of the normalized toroidal flux. Simulations with two (electrons and deuterium), three (with addition of carbon) and four (with addition of the fast deuterium) kinetic species were carried out. Electromagnetic effects were included in simulations by considering both fluctuations of perpendicular and parallel magnetic field.

Linear simulations identified the Ion Temperature Gradient (ITG) mode, Micro Tearing Mode (MTM) and Electron Temperature Gradient (ETG) modes as most unstable at various scales (shown in Figure 1). The high frequency fast ion mode previously observed in reference scenario 1 simulations [3] was also found in linear simulations and identified as Toroidal Alfven Eigenmode (TEA).

Similar to simulations for the reference scenario 1 [3], TAE was found to significantly complicate nonlinear simulations causing oscillations of the heat flux. Parameters of the fast ion profile were modified to stabilize the mode in nonlinear simulations and obtain converged values for the heat flux. Unlike the scenario 1, where heat flux was found to be much lower than heating power at ρ_{tor}=0.5, in this case turbulent heat flux at ρ_{tor}=0.5 was found to be three times larger than the total heating power of 41 MW. A small (10%) decrease of electron and ion temperature gradients was sufficient to recover expected heat fluxes.

To address discrepancy with scenario 1, linear and nonlinear simulations at additional radial locations in the core (ρ_{tor}=0.3-0.7) were carried out, in particular showing similar results at ρ_{tor}=0.6 to those published in [3]. Linear simulations demonstrated highest growth rates at ρ_{tor}=0.5, while nonlinear simulations at every other location resulted in the heat flux much lower than heating power. Nonlinear heat fluxes are shown in Figure 2.

The heat flux was found to be sensitive to small changes of the input gradients of both electron and ion temperature, suggesting a mix of ITG and Trapped Electron Mode.

Overall, the modeling results suggest that the profiles produced by the transport modeling are self-consistent in terms of the core turbulence and in fact a steeper gradient could be possible at most core radial locations.

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[1] JT–60SA Research Unit 2018 JT–60SA Research Plan. Research Objectives and Strategy, v4.0
[2] L. Garzotti et al 2018 Nucl. Fusion 58 026029
[3] A. Iantchenko et al 2024 Nucl. Fusion 64 026005

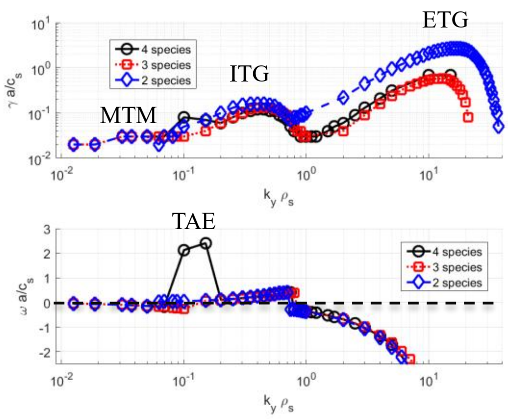

Figure 1. The growth rate (top) and frequency (bottom) of the fastest growing mode depending on the binormal wavenumber. Positive frequency corresponds to the ion diamagnetic drift direction. Different lines correspond to different number of kinetic species used in the GENE simulation.

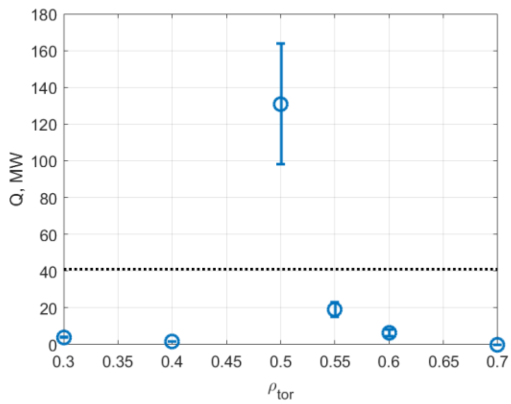

Figure 2. Total heat flux depending on the radial position of the flux-tube center. Errorbars correspond to the standard deviation of the heat flux in the stationary phase. The dashed black line corresponds to the total heating power.