

Microturbulence simulations in optimised stellarators

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Recent findings suggest that so-called quasi-isodynamic stellarators, where the diamagnetic frequency ω_{*a} and the bounce-averaged magnetic precession frequency $\overline{\omega_{da}}$ have opposite signs everywhere on the flux surface, benefit from enhanced linear stability towards ordinary trapped-electron modes and other instabilities in large regions of parameter space. It was found analytically [1, 2] in the electrostatic and collisionless limit that this enhanced stability is due to the kinetic electrons, which draw energy from the modes instead of driving the instabilities. These results were also confirmed numerically [3] by studying instabilities driven by a density gradient and both ion and electron temperature gradients in various magnetic field configurations. It is particularly interesting to compare different stellarators that are already optimised with respect to neoclassical confinement, and investigate their behaviour towards microinstabilities, depending on their respective degree of quasi-isodynamicity. Two current experiments that are known or are expected to have predominantly turbulent transport—the Helically Symmetric Toroidal Experiment HSX (Fig. 1, with an aspect ratio of $A = 8$) and Wendelstein 7-X (W7-X, Fig. 2, with an aspect ratio of $A = 10$)—are thus chosen for this work.

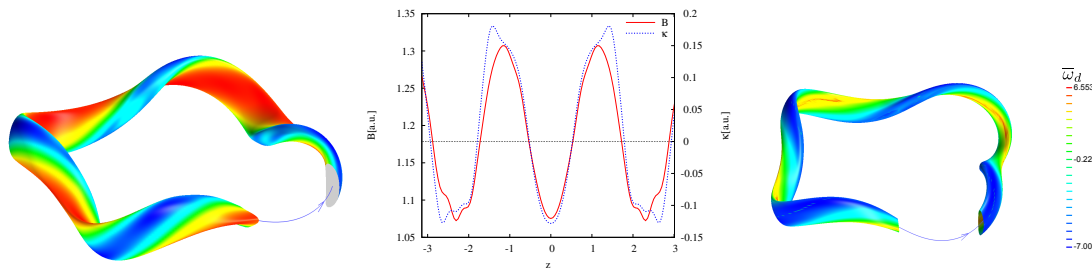


Figure 1: Geometry details of the bean flux tube of HSX: Left: Strength of the magnetic field B at the outer most flux surface. Red indicates the maximum, blue the minimum of the field. Middle: Magnetic field B and curvature κ along the field line for the bean flux tube. Right: Bounce averaged magnetic curvature as function of bounce point on the $s = 0.5$ surface. Negative values denote good average curvature, positive values bad average curvature.

W7-X is significantly more quasi-isodynamic than HSX, implying that the stability criterion $\omega_{*a} \cdot \overline{\omega_{da}} < 0$ is met for more orbits than in HSX (c.f. Figs. 2 and 1 on the right, respectively), so that more trapped particles experience average “good curvature”. Also the regions of low

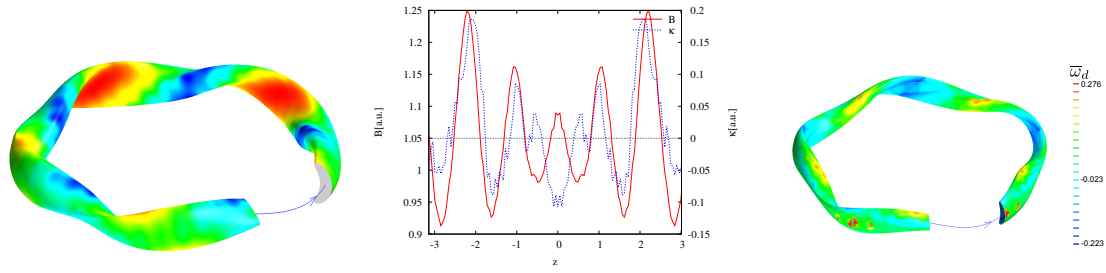


Figure 2: Geometry details of the bean flux tube of W7-X: Left: Strength of the magnetic field B at the outer most flux surface. Red indicates the maximum, blue the minimum of the field. Middle: Magnetic field B and curvature κ along the field line for the bean flux tube. Right: Bounce averaged magnetic curvature as function of bounce point on the $s=0.5$ surface. Negative values denote good average curvature, positive values bad average curvature.

magnetic field, i.e. where the trapped particles are located, barely overlap with the regions of bad curvature, whereas there is almost perfect overlap in HSX, see the middle Figs. 2 and 1. W7-X is therefore expected to be more stable towards modes with kinetic electrons than HSX. To investigate the effect of the geometry on microinstabilities, linear and nonlinear simulations are performed with the GENE [4] code. Two different stellarator-symmetric flux tubes were used for both devices: the bean flux tube where the centre of the flux tube is located in the so-called bean-shaped poloidal plane, and the triangle flux tube where the centre of the flux tube is located in the triangular plane. The linear investigations were carried out using a fixed combination of gradients, while the normalised binormal wave number $k_y \rho_s$ was varied over a large range (ρ_s denotes the sound gyro radius). On the left of Figs. 3 and 4 the results of ion-temperature-gradient (ITG) driven modes with adiabatic electrons are presented. The ion temperature gradient was $a/L_{Ti} = 3$ and the density gradient was $a/L_n = 1$, where a is the minor radius of the device and L_x is the respective gradient scale length. It can be seen that W7-X is slightly more stable in both flux tubes, likely due to the very narrow and shallow regions of bad curvature. As expected, these modes propagate in the ion diamagnetic direction, $\omega \omega_{*i} > 0$, and the mode structure in W7-X clearly hints at curvature driven modes. If kinetic electrons are taken into account (see middle plots of the same figures) the growth rates are increased slightly in HSX, but are decreased in W7-X. This stability feature of W7-X is attributed to the enhanced degree of quasi-isodynamicity and can also be observed for the trapped-electron modes with an electron temperature gradient of $a/L_{Te} = 1$ and a density gradient of $a/L_n = 2$. Again the bean flux tube is slightly more unstable than the triangle flux tube. While the modes that are found in HSX propagate both in the ion and electron diamagnetic direction, the modes are still only

In this work, the two neoclassically optimised stellarators HSX and W7-X were compared with respect to linear and nonlinear microstability. HSX shows a destabilisation by kinetic electrons

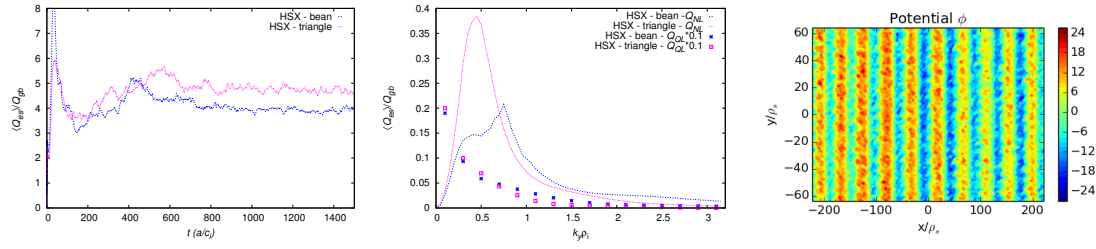


Figure 5: Simulation of ITG turbulence with adiabatic electrons in HSX. Time trace (left) and spectrum (middle) of the ion heat flux. Right: Contour plot of the electrostatic potential ϕ

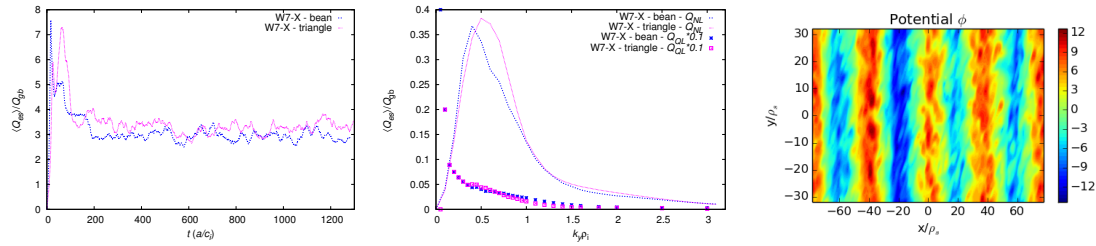


Figure 6: Simulation of ITG turbulence with adiabatic electrons in W7-X. Time trace (left) and spectrum (middle) of the ion heat flux. Right: Contour plot of the electrostatic potential ϕ

for ITGs and significantly higher growth rates for TEMs than W7-X. Nonlinearly, these enhanced growth rates translate into slightly elevated ITG heat flux levels compared with W7-X for adiabatic electrons. Nonlinear simulations including kinetic electrons are under way.

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