The confinement of helium tokamak plasmas, impact of electron heating, turbulent transport and zonal flows

P. Manas[1], C. Angioni[1], A. Kappatou[1], F. Ryter[1], P. A. Schneider[1]
and the ASDEX Upgrade Team
[1] *Max-Planck-Institut für Plasmaphysik, D-85748 Garching, Germany*

Helium plasmas in tokamaks are regularly observed to have a reduced confinement with respect to deuterium plasmas [1, 2], inconsistent with the gyro-Bohm scaling of turbulent transport. A theoretical explanation of this confinement reduction is required to reliably predict the plasma confinement in the initial non-nuclear phases of ITER operation and also extend the understanding of the isotope effect, hydrogen and helium having the same Larmor radius.

Pairs of L- and H-mode plasmas in He and D have been produced in ASDEX Upgrade, where a large variation of the electron to ion heating fraction is obtained with the ECRH and NBI systems. While all the D plasmas exhibit good confinement, the stored energy in He plasmas is observed to increase from 70% to 100% of that of D with increasing ratio of the electron to ion heating. Two regimes are identified, one characterised by strong ECRH heating and low electron density where He shows confinement as good as D, and one characterised by strong NBI heating, where He shows a significant degradation of the confinement. These two regimes were analysed with the transport code ASTRA, and the microinstabilities and the saturated turbulence were simulated with the gyrokinetic code GKW.

When ion heating is dominant, in the edge region, ETGs are found to be strongly unstable in the simulations, and thermal coupling limits the increase of the ion temperature when moving from D to He. In the core, the electron and ion temperatures are very similar, but lower in He compared to D, due to increased transport in He. Nonlinear electromagnetic simulations of the D plasma show strong zonal flow activity in ion temperature gradient (ITG) turbulence whereas for a companion simulation where D is replaced by He, a factor of 2 increase of the ion heat flux is observed, with relatively weaker zonal flow levels. When electron heating is dominant, in the edge region the electron temperature largely exceeds the ion temperature and allows an increase of the ion and electron temperatures when moving from D to He due to reduced thermal coupling and relatively stable ETGs. In the core, strong TEM turbulence is obtained in the simulations, with weak zonal flow activity and heat fluxes lower in He than in D. These results confirm a weaker impact of zonal flows in TEM turbulence and for the first time relate them to the different properties of He confinement. The strong impact of zonal flows coupled to electromagnetic effects on the turbulent transport level and on the breaking of the gyro-Bohm scaling presents analogies with recent results on the isotope effect of H [3].

References

[1] D. C. McDonald *et al*, Plasma Physics and Controlled Fusion **46**, 519 (2004)
[2] F. Ryter *et al*, Nuclear Fusion **49**, 062003 (2009)
[3] J. Garcia *et al*, Nuclear Fusion **57**, 014007 (2017)