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The key to the I-mode confinement regime

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The I-mode[1,2] is an improved energy confinement regime of tokamak plasmas usually achieved by using magnetic configurations with the ion grad B drift pointing away from the active X-point, i.e. the so-called unfavorable configurations in terms of H-mode access. The I-mode is ELM-free whilst not suffering from high impurity content making it an attractive confinement regime for future devices, such as DEMO or ARC. I-modes are characterized by a temperature pedestal but no density pedestal. A transport barrier induced by a strong ExB shear flow as in the H-mode should reduce both, particle and heat transport. Thus, other mechanisms of turbulence suppression must be important.

We present such an alternative mechanism leading to the observed selective suppression of electron heat transport which bases on drift-wave turbulence at low collisionality. Compared to density fluctuations electron temperature fluctuations are additionally dissipated by conductivity, which is more effective at higher conductivity and hence at higher temperatures. This allows the seemingly decoupling of heat and particle transport at rising temperatures. However, to achieve this regime, the ion temperature gradient has to be rather flat, which is actually measured around the separatrix in ASDEX Upgrade. With the presented mechanism we can explain the small window of operation at small magnetic fields [3,4] and the difficulties to go into detachment [5] in this regime.

Simulations in such a regime of edge turbulence have been carried out with the global three-dimensional gyrofluid electromagnetic turbulence code GEMR [6] at ASDEX Upgrade parameters. The most prominent feature of I-mode turbulence, the so-called weakly coherent mode (WCM) [7-10] is clearly revealed in the simulations. Turbulence suppression at larger and smaller scales have been investigated in detail. In the simulations large-scale structures ($k < k_{WCM}$) are suppressed by phase randomization and the small scales ($k > k_{WCM}$) by finite Larmor radius stabilization.

Phase randomization is a signature of magnetic field line stochastisation, which is only beneficial at moderate plasma beta. At too high plasma beta strong electromagnetic transport can be induced. A low collisionality is needed for the thermal decoupling of ions and electrons at the separatrix. A window in plasma beta and collisionality can explain the small window of operation at small magnetic fields [3,4]. When approaching detached conditions, the collisonality increases with increasing plasma density. Ions and electrons are thermally coupled and the ion temperature gradient steepens up. This can lead to a resuscitation of the ITG turbulence, finally leading to an I-Lback-transition.

Furthermore, the simulations show several features of the I-mode. The simulated density fluctuations show highly intermittent behavior with strong bursts appearing from time to time as observed in the experiment [4,11]. These bursts exhibit precursors, connected to the WCM as observed in the experiment [4,11]. Geodesic acoustic modes (GAMs) appear in the simulations as observed in the experiment [8,9].

This work has been recently published in Nuclear Fusion [12].

References

[1] F. Ryter et al. Plasma Phys. & Controlled Fusion 40, 725 (1998)
[2] D.-G. Whyte et al. Nucl. Fusion 50, 105005 (2010)
[3] A. E. Hubbard et al. Nucl. Fusion 56, 086003 (2016)
[4] T. Happel et al. Plasma Phys. & Controlled Fusion 59, 014004 (2017)
[5] M. Reinke et al., Nucl. Fusion 59, 046018 (2019).
[6] A. Kendl et al. Phys. Plasmas 17, 072302 (2010)
[7] A. E. Hubbard et al., Phys. Plasmas 18, 331 (2011).
[8] I. Cziegler et al., Phys. Plasmas 20, 055904 (2013).
[9] P. Manz et al., Nucl. Fusion 55, 083004 (2015).
[10] X. Feng et al., Nucl. Fusion 59, 096025 (2019).
[11] T. Happel et al. 2016 Nucl. Fusion 56 064004 (2016)
[12] P. Manz et al. 'Physical Mechanism behind and Access to the I-mode Confinement Regime in Tokamaks', Nucl. Fus. (in press)