Stabilization of Microturbulence by Fast Ions in ASDEX Upgrade

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EXTENDED ABSTRACT

Tokamaks are devices used to confine a fusion fuel mixture heated to high temperatures in the range of hundreds of millions of degrees, arriving in a state of matter called plasma. Several auxiliary systems are used for this purpose. They include Neutral Beam Injection (NBI) and electromagnetic waves. The largest tokamak up-to-date, aiming to achieve self-sustained nuclear fusion, is the International Thermonuclear Experimental Reactor (ITER) [1] shown in Fig 1. It is presently under construction in Cadarache, France.

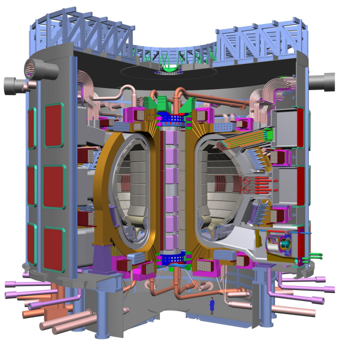

Fig. 1 Cross section of the ITER tokamak [1]. Its reactor core consists of a vessel used to contain the gas and several magnetic coils used to generate the magnetic field that confines the plasma.

A. Introduction

It has been experimentally found that transport of particles and heat in tokamaks is larger than expected when compared to neoclassical theoretical predictions, *i.e.* based on Coulomb collisions with the addition of toroidal geometry. It is thought that this is due to the presence of microinstabilities which are self-organized small-scale turbulent plasma fluctuations that can lead to transport of particles and heat. Given that a steady state is obtained when sources and transport are in balance, microturbulence is believed to be a critical player in the quality of the confinement. In order to improve the confinement of the plasma and avoid losses of particles and heat to the vessel, mechanisms of stabilization of microturbulence such as those studied in this work are of particular interest.

B. Ion Cyclotron Resonance Heating (ICRH)

One of the main auxiliary heating systems foreseen for ITER is the Ion Cyclotron Resonance Heating (ICRH). In this system, powerful electromagnetic wave antennas are used to transfer energy to the plasma.

It has been suggested [2,7-8] that the use of ICRH has helped to increase the ion-bulk temperature in the Joint European Torus (JET) tokamak by stabilizing microturbulent effects. In that case, a relaxation of ion pressure profile stiffness is believed to be induced by microturbulence stabilization, arising in turn from fast ion suprathermal pressure gradients.

The goal of the present work is to study the impact of fast ions, generated by ICRH, on microturbulence. Our methodology is similar to that in [2] and is based on extensive simulations of discharges carried out on the ASDEX Upgrade (AUG) tokamak, in Germany using state-of-art fusion simulations codes.

C. Method

The three main codes used in the work are PION [3], FIDO [4] and GENE [5]. The Finite Ion Drift Orbit (FIDO) code and the PION code are used to compute Ion Cyclotron Resonance Heating in tokamaks. They are used to study the waves, interaction with the plasma and the profile of ICRH power deposition in the plasma. The output of these codes is used as input in GENE, enabling us to quantify the impact of the presence of fast ions in the stabilization of microturbulences. The Gyrokinetic Electromagnetic Numerical Experiment (GENE) code is used to compute gyroradius-scale fluctuations, including microturbulence, and the resulting transport coefficients.

GENE solves for the distribution function *f* in (x,v) space and time. Integrating *f* over velocity space yields the equation

$$\frac{\partial n}{\partial t} + v_E \cdot \nabla n_0 + v_E \nabla \cdot n + n_0 \nabla \cdot v_E + \frac{2}{m\Omega B^2} B \times \nabla B \cdot \nabla \mathrm{p} = 0 \qquad (1)$$

for the time evolution of the density n. Here n_0 stands for the initial density, v_E for the ExB drift velocity, m for the species mass, Ω for the cyclotron frequency, B for the magnetic field and p for the normalized pressure.

In the present work, we solve the linearized version of Eq. (1), which is less computationally expensive. This study yields the growth rate and frequency of different unstable plasma waves for a broad parameter range consistent with the experimental conditions of the AUG discharges under consideration.

D. Results

The two AUG discharges we consider in this work are discharges 31563 and 31562 with combined NBI and ICRH heating. They were prepared in the same way except for the on-axis magnetic field to vary the ICRH resonance position and the concentration of He-3 ions resonant with ICRH waves.

Figure 2 shows the measured ion temperature T_i for these discharges together with T_i for a reference discharge 31555 without ICRH heating. The results show an increase from 3 keV to 5.5 keV in central T_i with ICRH as compared to 31555 without ICRH.

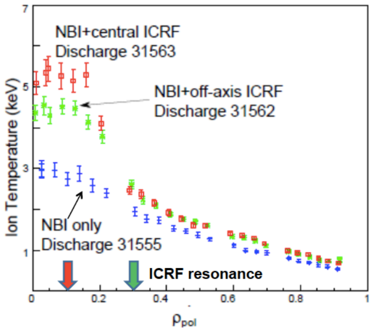

Fig. 2 Ion temperature T_i profiles for AUG discharges 31562, 31563 and 31555 [6]. T_i in discharges 31562 and 31563 is higher than what it is expected from bulk ion heating alone. 1 keV = 11604525 K.

Figure 3 shows the fast ion pressure profile as calculated with FIDO. Discharge 31563 has a steeper fast ion pressure profile although the heating power is the same for both cases, $P_{ICRF} = 3.5$MW.

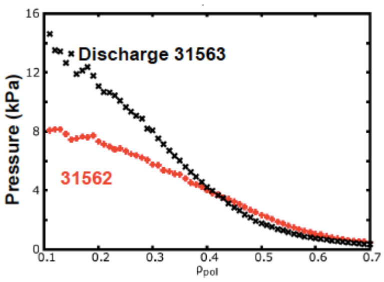

Fig. 3 Pressure profile of ^{3}He ions for discharges 31562 and 31563 calculated by FIDO.

A linear analysis done with GENE showed that fast ions have a strong impact on the instability growth rate of Ion Temperature Gradient (ITG) instability, as it can be seen in figure 4. In particular, our results indicate a dual impact of fast ions in the instability growth rate, affecting both ITG and Kinetic Ballooning Mode (KBM). The presence of fast ions (red and black curves) not only diminishes the value of the instability growth rate at low betas, but it also delays the onset of the rapid increase observed at higher betas, associated with the KBM instability, which is related to fluid dynamics activity. Here, the beta is the plasma pressure normalized to the magnetic pressure. As expected from KBM theory, a large impact of the safety factor q is also found. The parameter q measures the ratio of the toroidal and poloidal magnetic fields used to confine the plasma. In order to make accurate predictions, this parameter needs to be accurately measured.

E. Summary

In this work, we have studied the effect of fast ions on microturbulence stabilization for two specific AUG discharges with combined NBI and ICRH heating. According to the GENE simulations in linear mode, the presence of fast ions has a stabilizing effect on microinstabilies and could be responsible for the ion stiffness reduction associated with suprathermal pressure gradients.

Further work involves performing nonlinear simulations and comparing the simulated values of particle and heat fluxes with the ones found in reference [6].

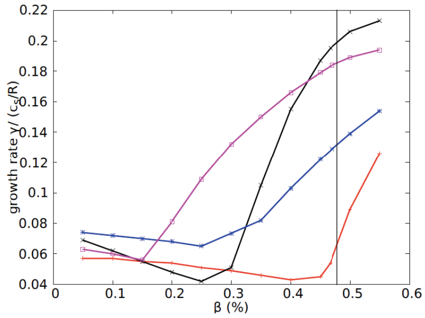

Fig. 4 Instability growth rate of discharge 31563 with and without fast ions. The KBM threshold is characterized by the sharp upturn in the growth rate as a function of beta. The vertical line represents the experimental thermal beta. Red and black curves represents simulations with fast ions for safety factor q equals to 1.6 and 2.0, blue and pink are simulations without fast ions for q equals to 1.6 and 2.0

F. ACKNOWLEDGEMENT

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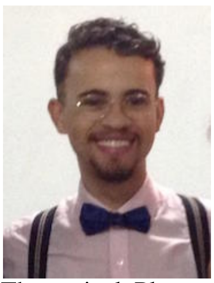
Author biography



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